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LEVEL II

APPROACH LIGHT AIMING CRITERIA

Charles A. Douglas

DECEMBER 4, 1978

FINAL REPORT

Prepared for

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16. Abstract

A method of determining the elevation setting angles for approach lights based upon fundamental principles has been developed. This method considers the effects of the applicable decision height, the required visual range, the glide slope angle, the distance of the light from the threshold, and the vertical beam spread of the light.

This method, defined as the visual segment method, has been compared with other methods and found to be preferable.

Elevation-setting-angles have been computed for the lights of the MALSR and ALSF-2 approach-light systems when lamped with the types of lamps presently in service.

The suitability of the intensity distribution characteristics of the lights currently used in U.S. approach-light systems has been analyzed and possible changes noted.

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METRIC CONVERSION FACTORS

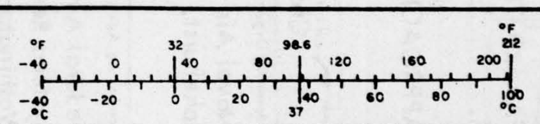
Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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APPROACH-LIGHT AIMING
CRITERIA

1. INTRODUCTION

1.1 Scope

This report gives the results of an analysis of the several criteria used in determining the elevation angles at which the beams of the lights of a system of approach-lights should be set. This study was conducted as part of contract N68335-78-C-2022 with Quanta Systems Corporation, Rockville, Maryland. It consists of a review of the literature, a historical review and an analysis of past and present elevation-setting criteria, an analysis of the fundamental principles involved in the determination of the optimum elevation settings of the lights in the system, and an evaluation of the effects of several criteria on the performance of approach-light systems equipped with lights of the several types now in service. Four Appendices containing background information are included.

1.2 Objective of this Study

The objective of this study is to develop a method by which the elevation angles at which the lights of an approach-light system are set to obtain the maximum guidance from the system.

1.3 Historical Résumé of Aiming Criteria Used

> NOTE: This Section contains a résumé of the aiming criteria used over the years. An analysis of the effects of these criteria is given in Section 3, after the principles involved in determining the optimum elevation settings are developed in Section 2.

1.3.1 The Early Years (1925-1935)

During the early days of night flying, the lights used as visual landing aids were usually omnidirectional lights without optics and aiming was not required. As development progressed, the designers realized that the light emitted from the omnidirectional lights in directions near the vertical was wasted and that higher intensities could be obtained, with no increase in energy consumption, by concentrating the light into a region near the horizontal. Since radio aids were not then in general use, the lights provided 360° beams of relatively constant intensity in azimuth. In the U.S., boundary,

range, obstruction and the early runway-edge lights (then called contact lights) provided 360° coverage in azimuth with their maximum intensities at an elevation of about $3\frac{1}{2}°$, a typical angle of approach.

1.3.2 Beam Axes Set at a Single Angle of Elevation (1935-1945)

With the development of electronic aids in 1932-33, it became possible to bring an aircraft into approximate alignment with the runway without the use of visual aids. It was then possible to use projectors aligned in the direction of approaching aircraft instead of lights having an essentially uniform distribution in azimuth. The first approach lights of record were installed at Newark Airport in 1935 [1]. Three lights were installed at 500-foot intervals on the extended runway centerline. The lights were 18-inch airway course lights with the inner lenses removed to obtain wider beams. No record of their elevation settings was found.

The first operational approach-light system in the U.S. was the neon "ladder." This system was composed of 14 6-foot long neon lights mounted horizontally at 100-foot intervals on the left-hand side of the approach zone. The horizontal intensity distribution of these lights was a cosine curve. Hence, no toe-in was required. At the time these lights were first installed electronic guidance in the vertical plane was not available, and the elevation setting of the light beams is believed to have been that of the nominal angle of descent. No information on the elevation setting during this period was found in the literature search. However, during the preparation of this report, the author found, by chance, the tool he had constructed to set the approach lights during the 1940 tests at the CAA Experimental Station, Indianapolis [2]. This tool was adjusted to obtain an elevation setting of $3\frac{1}{2}°$. *

The elevation setting criterion of the neon lights was changed about 1950. See Section 1.3.3.

During the years of World War II, the U.S. Army Air Corps and the Navy used a parallel row approach-light system comprised of Bartow Type D-1 lights. These lights were elevated 3° and toed in $3\frac{1}{2}°$, and later 5°. The setting was found to be too low, and a change in the elevation setting criterion was made [3, Appendix 1;]. (See Section 1.3.3)

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* The search for information on the elevation settings used at different times or with different approach-light systems was particularly frustrating. The lengths and widths of systems, the spacing of the lights in the system, their color, and in some instances, their peak intensities, and even horizontal and vertical beam spreads, are given in the papers and reports on approach lights. However, most of these publications, including those of the author, contain no information on angular settings.

1.3.3 Beam Axes Set to Intersect Glide Slope a Fixed Distance Ahead of Lights (1945 to date)

During the period 1945-1950, efforts to obtain visual landing aids suitable for use in very low visibilities were extensive. The deficiencies observed in World War II, the improvement in electronic guidance, and the increase in commercial air traffic added impetus to the efforts. In the U.S., the Landing Aids Experiment Station (LAES) was established in Arcata, California, under joint sponsorship of the Air Force, Navy, and Civil Aeronautics Administration [4, 5]. Numerous configurations of approach lights using lights with different intensity distributions were tested.

The slope-line system [6], and some other systems, were aimed so that the beam axes of the lights intersected the glide slope 1200 feet ahead of the lights for the LAES tests [4]. This criterion was used for the slope-line systems which were installed at some major airports during the period 1948-1950 (no direct information available) and for all systems tested in the comparative tests of approach-light systems conducted in 1951 [7, p. 12, 16, 57]. During this period the elevation-setting criterion of the neon approach-light system was changed from that described in Section 1.3.2 to one which the elevation setting was such that the beam axis intersected the glide slope 1000 feet ahead of the light [8].

For reasons explained in Section 2.4, the distances of 1200 feet and 1000 feet, quoted above, were changed to 1600 feet in 1951 or 1952 [9]. (No reference was located relating to the time the distance of 1600 feet ahead of the light was adopted for the slope-line system.)

The criterion of directing the beam axes of approach lights to intersect the glide slope 1600 feet ahead of the light is still being used for the one remaining neon light system [9], for high intensity incandescent approach lights (ALS), for medium intensity incandescent approach lights, and for the sequence flashers [10]. No account has been taken of the effects of differences in the intensity distributions of the lights used and differences in the minimum visibility conditions in which the systems are expected to provide visual guidance upon the optimum angular setting of the beams.

The lights of the slope-line system were aligned with no toe-in [11]; of course, the lights of centerline systems are aligned with no toe-in, as are the lights of their crossbars [10].

1.3.4 Movable Beams Adjusted to the Weather Conditions

The Bartow multi-row system of approach lights and several variants tested at LAES were equipped with lights, the beams of which were adjusted in azimuth and elevation in accord with the prevailing visibility conditions [5, 11, 12].

1.3.5 Beam Axes Directed so that Light Beams Cover a Specified Flight-Path Envelope

When this criterion is applied, the locations of the boundaries of the beam are of more consequence than is the location of the beam axis with respect to the glide slope. The beam axis is so directed that for all distances above a certain minimum distance, referred to as the designated distance, the boundaries of the flight-path envelope lie within the boundaries of the light beam. The criterion was first used in aiming the Funnel System installed at LAES in 1947 [3, 11]. It was also used in the parallel-row system using fixed wide-beam lights tested there [12].

This criterion was also used in the later part of the tests of the slope-line system at the Naval Air Test Center and for the Navy composite system installed there in 1951 [13].

This criterion was also used by the United Kingdom in the Calvert system [14] after the sodium vapor lamps were replaced by incandescent lamps.

At its Sixth Session (1957), the Aerodromes, Air Routes and Ground Aids Division (AGA) of ICAO used this criterion in preparing Guidance Material for inclusion in Attachment B (the Green Pages) to Annex 14 [15]. In this material, the intensity distribution of the U.S. 300-watt approach light was used as an example of the application of this material to "a well designed approach-light fitting."

The Visual Aids Panel at its Fourth Meeting (1966) used this criterion in their development of beam-spread and angular-setting requirements of approach and runway lights [16]. This work was approved and published in the Aerodrome Manual, Part 4, Visual Ground Aids in 1969 [17]. The values given in Table V-1 of Annex 14, Fifth Edition, Amdt 27 [18] are the result of this work. This material was revised by a Working Group of the Visual Aids Panel in the early 1970's taking into account current data relating to the flight-path envelope and current and forthcoming operations in Category III visibility conditions [19]. The revised material is contained in the Aerodrome Design Manual, Part 4, Visual Aids [20], and in Table 5-1 of Annex 14, Seventh Edition, Amdt 31 [21].

In each case the dimensions of the flight-path envelope were based upon current knowledge of the accuracy of the electronic aids and the accuracy with which the guidance provided by these aids could be followed. The designated distances*, stated or implied, were: a) Approximately 700 feet for the systems tested at LAES, based upon a visual segment of 600 feet and a cockpit cutoff angle of about 30°** [3]; b) 1200 feet for the systems installed at NATC [13]; c) 1500 to 2000 feet by Calvert [14]; d) 2000 feet

* See Section 2.2 for explanation of "designated distance."

** With the pilot leaning forward and looking toward the side of the aircraft.

at the Sixth Session of AGA, based upon a cockpit cutoff-angle of 10° and a 250-foot decision height (DH) (then designated as "critical height") [15]; e) 1300 feet by the Fourth VAP and the studies made thereafter by ICAO [16, 19].

In each case the elevation of the beam axis was chosen to satisfy the criterion that the beam extends from the upper boundary of the region of guidance down to an angle of 2° or less. (An approach light having a suitably wide vertical distribution was assumed.) In none of these cases was the beam axis directed at the point where the horizontal plane through the DH intersected the glide slope.

1.3.6 Method Proposed in the "Engineering Requirement" for this Study

The following method was proposed for consideration in the Engineering Requirement for this study:

1. MALSR.
   a) Aim the flashing light at station 16 at the CAT I DH. Aim the remaining flashers at the same angle.

   b) Aim the steady burning light bars at station 14 at the DH. Aim the remaining steady burning light bars at the same angle.

2. ALSF-2.
   a) Aim the flashers at station 17 at the CAT I DH. Aim the flashers at the other stations at the same angle.

   b) Aim the steady burning lights of station 10 through 24 at the same angle as the flashing lights of the system.

   c) Aim the steady burning lights of station 5 at the CAT II DH. Aim the lights of stations 1 through 9 at the same angle as station 5.

   d) Aim all red side row barrettes at the same angle as the steady burning lights.

   e) Aim 1/2 of the threshold lights (every other one) at the CAT I DH. Aim the other half of the threshold lights at the CAT II DH.

2. FACTORS DETERMINING THE OPTIMUM ELEVATION OF THE BEAM AXES

2.1 Background

The section consists of the development of a methodology for obtaining the optimum elevation of the beam axes of the lights of an approach-light system from a general solution based upon fundamental principles.

The optimum elevation of the beam axis of an approach light is a function of several parameters. The primary factors are:

a) The decision height, DH;

b) The glide slope or angle of approach;

c) The distance from threshold at which the glide slope intersects the runway;

d) The minimum visual reference required at the decision height;

e) The flight-path envelope;

f) The cockpit-cutoff angle;

g) The vertical beam spread of the approach-light fitting; and

h) The distance of the approach light from the threshold.

Note that only geometric quantities, lengths and angles, are factors in determining the optimum elevation of the beam axis and that light intensity and minimum atmospheric transmittance (or visibility) are not involved. It is, however, essential that the intensity of the light be sufficient to provide a visual range which will ensure the required visual reference during the specified minimum atmospheric transmittance or visibility conditions.

As is evident from Figure 1, the distance, d, from the threshold at which an aircraft on glide slope reaches the decision height, H, is given by the equation

$$d = (H/\tan \theta) - t \qquad (1)$$

where

θ is the glide slope, and

t is the distance of the intersection of the glide slope with the runway (aiming point) from the runway threshold.

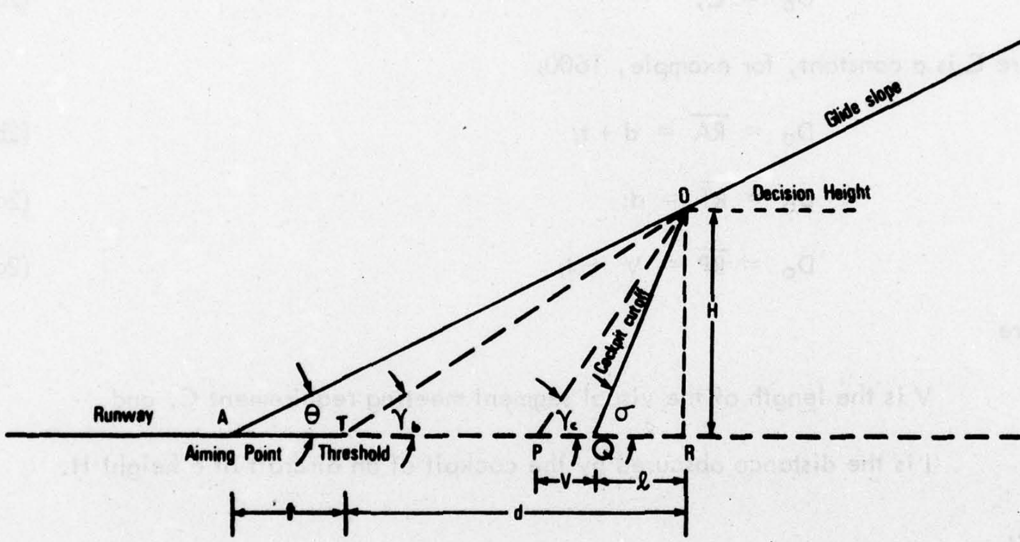


Figure 1. Geometric Relations Used in Computing the Designated Distance for the Visual Segment (VS) Method

The minimum visual reference required at the DH must be established before the optimum beam elevation can be determined. There is a wide range of views concerning this requirement, some of which are:

a) A light must be visible from a fixed distance ahead of the aircraft;

b) The aiming point must be visible from the DH;

c) The threshold must be visible from the DH;

d) A 500-foot segment of the approach-light system must be visible; and

e) One or more approach lights must be visible.

2.2 The Designated Distance

The light nearest the aircraft, at point 0, which satisfies the stated visual reference requirement will be called the "critical light" and the distance, measured horizontally between 0 and this light, the "*designated distance*, symbol D_o." Thus, depending upon the visual reference requirement, the critical light would be at points A, T, P, or Q for visual reference requirements b, c, d and e, respectively. The designated distances for these four requirements are, in order of the requirements:

$$D_o = C, \tag{2a}$$

where C is a constant, for example, 1600;

$$D_o = \overline{RA} = d + t; \tag{2b}$$

$$D_o = \overline{RT} = d; \tag{2c}$$

$$D_o = \overline{RP} = V + l; \tag{2d}$$

where

V is the length of the visual segment meeting requirement C, and

l is the distance obscured by the cockpit of an aircraft at a height H.

Thus,

$$D_o = V + H/\text{Tan}\ \sigma, \tag{2d'}$$

where

σ is maximum downward angle of view over the nose of the aircraft.

For requirement e,

$$D_o = \overline{RQ} = l = H/\tan\sigma, \tag{2e}$$

or, preferably,

$$D_o = l + 100. \tag{2e'}$$

The angle at which the critical light is viewed, γ, is then

$$\gamma = \tan^{-1}(H/D_o) \tag{3}$$

where

D_o is determined from equation 2a, 2b, 2c, 2d, or 2e as appropriate. The angles of view for visual-reference requirements b and c are illustrated on Figure 1.

2.3 Visual-Range Requirements

The distance from the aircraft, point O, to the critical light is the minimum slant range for which the system will provide the required visual reference. Hence, if visibility from this point were the only criterion, the beam axis should be elevated to the angle γ.

NOTE 1: At the angles of elevation applicable to conventional aircraft, the difference in distance from point R to the critical light and the slant range is of the order of -2%.

NOTE 2: Fog density typically increases with height above the ground. For example, at Hanscom Field when the mean runway visual range (RVR) during periods of advection fog and stratus was just over a mile, at 100 feet elevation the "sensor equivalent visibility" was about three fourths mile and at 150 feet, one-half mile [22]. Similar results were obtained in slant visual range studies at NAFEC [23]. Thus, the designated distance must not be construed as a visibility minimum, for the system. The visibility minimum should be greater than the designated distance to obtain a reasonable probability of the pilot's being in visual contact with the critical light is to be expected.

Consideration must be given to the performance of the light at distances other than the designated distance. As the aircraft descends along the glide slope from point O, the distance between the aircraft and the critical light will decrease, the angle at which the light is viewed will increase, and, if the beam axis is directed toward point O, the intensity emitted in the direction of the aircraft will decrease. Experience over many years has shown that for conventional light fittings the decrease in the intensity required for the light to be visible caused by the decrease in viewing distance is considerably faster than the decrease in intensity caused by the increase in angle of view, and the light will become brighter and may even become glaring. Thus, a relatively sharp cutoff on the upper edge of the beam is desirable [6].

2.4 Beam Coverage Required for an Aircraft on the Glide Slope

During the period of 1940-1950 many lighting engineers considered that the vertical beam pattern of the light beyond (to the right of) point O of Figure 1 to be of no consequence, and approach lights were designed with beam patterns which did not provide for coverage at angles of view which were less than γ [24]. The 12.5-volt 250-watt, PAR56 lamps used in the slope-line system were designed to have a narrow vertical beam spread on this basis [6].

As illustrated in figure 2a, when the fog density is less than the maximum for which the system is designed, the critical light (at P) would be seen from point Z at a height (h) significantly greater than the DH if the intensity in the direction $\overline{PZ}$ were comparable to the intensity in the direction $\overline{PO}$. However, such is not the case with approach lights having a narrow vertical beam spread. Under this condition, the point Z is in the low-intensity or stray-light region of the beam. Flight tests of the 250-watt, narrow-beam lamp used in the slope-line system, and in other systems tested at NATC in 1951, showed that these lamps were unsatisfactory [4, p. 132 & figure 33; 25]. What is required is a lamp having a "substantially uniform" intensity between angles of elevation γ_c and γ_m. (See Appendix I for a discussion of "substantially uniform" intensity.) Preferably γ_m should be equal to θ the glide slope angle so that the entire length of the glide slope will be covered.

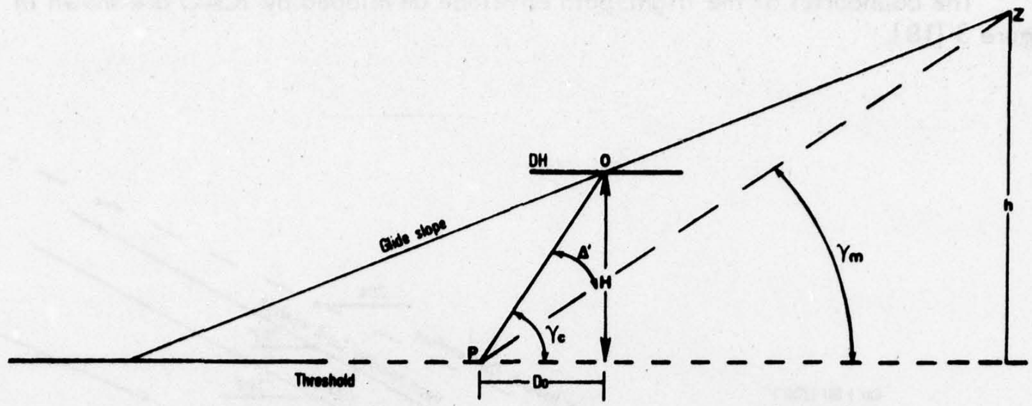
2.5 Beam Coverage Required for an Aircraft within the Flight-Path Envelope

Usually the aircraft will not be exactly on the glide slope, as has been assumed in the discussion of Section 2.4, but will be some distance above or below the glide slope. Boundaries have been established defining the expected limits of deviations, called the flight-path envelope. In order that the light cover the flight-path envelope, the elevation of the upper edge of the beam must be somewhat greater than γ_c (see figure 2b), to α, and that of the lower edge must be somewhat lower than γ_m to β. (This situation will be discussed quantitatively in Section 3.) The required beam spread of the light is then Δ. Lamps designed on this basis using a designated distance of 1200 feet were obtained, in a crash effort, to replace the 250-watt, narrow-beam lamps being used in the 1951 tests of approach-light configurations [13].

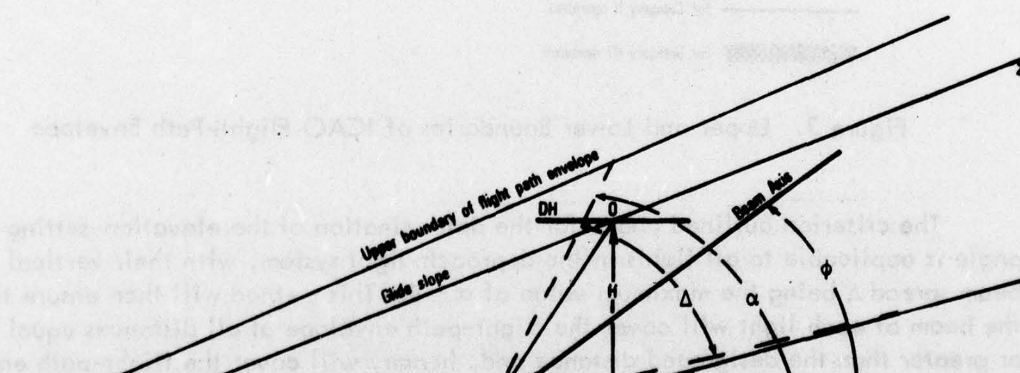
Note that in figure 2b the beam axis is not elevated to γ_c, directed toward the point O, but is elevated to a setting angle, ϕ, given by

$$\phi = (\alpha + \beta)/2 \tag{4}$$

Using this elevation-setting angle for a light having a vertical beam spread of Δ or greater insures that the beam of a light at P will cover the entire flight path envelope <u>for all distances greater than the designated distance D_o</u>.



2a. Aircraft on the Glide Slope



2b. Aircraft within the Flight-Path Envelope

Figure 2. Vertical Coverage Required from a Light

The boundaries of the flight-path envelope developed by ICAO are shown in figure 3 [18].

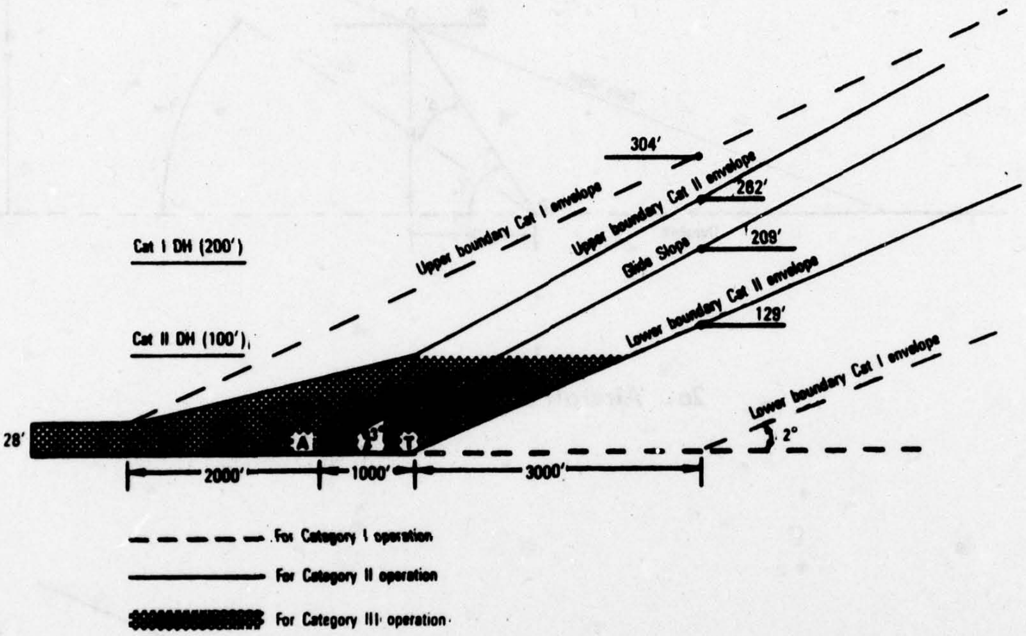


Figure 3. Upper and Lower Boundaries of ICAO Flight-Path Envelope

The criterion outlined above for the determination of the elevation-setting angle is applicable to all lights in the approach-light system, with their vertical beam spread Δ being the maximum value of $\alpha - \beta$. This method will then ensure that the beam of each light will cover the flight-path envelope at all distances equal to or greater than the designated distance and, hence, will cover the flight-path envelope for all fog densities equal to or less than the maximum fog density for which the system is designed.

This method of determining the elevation-setting angles was used with the wide-beam lamps which replaced the narrow-beam, 250-watt lamps in the approach-light tests of 1951 [13]. Flight tests comparing the two types of lamps showed that the difference in performance was significant, and the new lamps were used for the remainder of the approach-light tests. Lamps having the beam pattern of these new lamps were placed into service immediately by the Navy and the Air Force and somewhat later by the FAA and have been used in high-intensity approach-light systems in the U.S. for more than 20 years.

A theoretical comparison of the difference in performance of the two types of lamps showed that under most fog density conditions, the wide-beam lamps could be seen several seconds before the narrow-beam lamps even though the peak intensity of the wide-beam lamp was 30,000 candelas compared to 90,000 candelas for the narrow-beam lamp [26]. This anomaly led to the development and adoption of the concept of "representative intensity" as a measure of the performance of approach and runway lights. See Appendix II.

The method of determining beam spread and elevation-setting angles described in Section 2.5 has been used by ICAO since 1957 [15-21].

3. QUANTITATIVE ANALYSIS OF THE METHODS OF DETERMINING ELEVATION-SETTING ANGLES

In this Section an analysis is made of the effectiveness of the types of approach-lights used in the U.S. in covering the flight-path envelope agreed upon by ICAO when the beams of these lights are elevated in accordance with several of the methods described in this report.

3.1 Methods Analyzed

The methods of determining elevation-setting angles which will be analyzed are:

a) Directing the optical axes of the lights so that they intersect the glide slope 1600 feet ahead of the light. This is the method currently being used by the FAA, and it will be designated as the "FAA method."

b) Directing the optical axes of the lights in accordance with the method proposed in the Engineering Requirement for this study, designated as the "ER method." (See Section 1.3.6)

c) Elevating the optical axes of the lights as recommended in tables 2.1 and 2.2 of the Aerodrome Design Manual [20], designated as the "ICAO method."

d) Elevating the optical axes of the lights in accordance with the method proposed in Section 2.5 of this report to provide coverage over the current ICAO flight-path envelope [21], the upper and lower boundaries of which are shown in figure 3. This method is designated as the "VS method."

Elevation-setting angles for approach lights at several distances from threshold computed from these four methods are shown in Table I. The equations used in computing these angles are derived in Appendix III.

When the elevation-setting angles are based upon a stated decision height or approach-light system, these are indicated following the designation of the method. Thus, "ER-MALSR-200" indicates the elevation-setting angles are based upon the criteria given in the Engineering Requirement for the MALSR system and a decision height of 200 feet.

The final listing of the table, VS-modified, is a modification of Methods VS-100 and VS-200 to adapt these methods to the characteristics of the type Q20A/PAR56 light. The objectives of the modification were:

TABLE I

ELEVATION-SETTING ANGLES COMPUTED BY SEVERAL METHODS

Method of Computation	Station of Light ⟶	Threshold	400	800	1400	1600	2000	2400	2800
FAA		4.9	5.6	6.4	7.5	7.8	8.6	9.3	10.0
		For 200-foot Decision Height							
ER-MALSR-200		(1)	8.0	8.0	8.0	9.3	9.3	9.3	----
ICAO-CAT I & II (2)		4.5	4.5	4.5	5.0	5.5	5.5	6.0	6.0
VS-200 (3)		5.2	5.3	5.5	5.7	5.8	6.0	6.2	6.5
		For 300-foot Decision Height							
ER-MALSR-300	LHA	(1)	5.2	5.2	5.2	5.5	5.5	5.5	----
VS-300 (3)		3.7	3.9	4.2	4.4	4.7	5.0	5.3	5.5
		For 400-foot Decision Height							
ER-MALSR-400		(1)	4.4	4.4	4.4	4.5	4.5	4.5	----
VS-400 (3)		3.1	3.3	3.4	3.7	3.8	4.0	4.2	4.4
		For 500-foot Decision Height							
ER-MALSR-500		(1)	4.0	4.0	4.0	4.1	4.1	4.1	----
VS-500 (3)		2.9	3.0	3.1	3.3	3.4	3.5	3.7	3.9
		For 100- and 200-foot Decision Heights							
ER-ALSF-2		4.1/6.3[4]	13.8	13.8	10.2	10.2	10.2	10.2	10.2
ICAO CAT I, II, & III (2)		5.5	5.5	5.5	6.0	7.0	7.0	8.0	8.0
VS-100 + VS-200 from above		5.2[5]	5.9[5]	6.6[5]	5.7[6]	5.8[6]	6.0[6]	6.2[6]	6.5[6]
VS modified for Q20A/PAR56 lamp		6.1	6.3	6.6	7.0	7.1	7.4	7.6	7.9

NOTES:
(1) Not stated
(2) Elevations given to nearest 0.5 degree
(3) Elevation angles given are based upon lights having the vertical beam spreads listed in Table II.
(4) For alternate lights
(5) From VS-100 computations
(6) From VS-200 listed under "For 200-foot Decision Height"

a) To provide a smooth transition between the elevation-setting angles of the lights between the threshold and Station 800, which should cover the CAT I and II flight-path envelope under CAT II visibility conditions, and the lights beyond Station 800 which need cover only the CAT I flight-path envelope.

b) To make more effective use of the light beam. As will be shown later, this light has a vertical beam spread of 12° at 50% of peak intensity. Thus, when the elevation-setting angle is less than 6°, part of the light beam will be projected below the horizontal. An elevation-setting of 8° is selected for the light at Station 3000 as this setting places the beam axis 6° above the 2° slope of the lower boundary of the flight-path envelope. This is the maximum elevation-setting angle that can be used if the type Q20A/PAR56 lamp is to cover the entire CAT I flight-path envelope. An elevation-setting of 6.6° is required at Station 800 to cover the upper boundary of the CAT II flight-path envelope. The remainder of the setting angles provide a linear transition based upon these two angles.

3.2 Beam-Spread Requirements

Table II gives the minimum beam spreads of lights which will cover the entire flight-path envelope for all distances greater than the designated distance when the lights are elevated in accord with the elevation-setting angles listed in Table I.

TABLE II

MINIMUM VERTICAL BEAM SPREADS FOR
LIGHTS SET IN ACCORDANCE WITH THE METHODS LISTED IN TABLE I

Method of Computation of Elevation-Setting Angles	Beam Spread Required to Cover ICAO Flight Path Envelope (Degrees)
FAA	17
ER-MALSR-200	14*
-200	16**
-300	8
-400	7
-500	6
VS-200	10
-300	8
-400	5
-500	4
ER-ALSF-2	24*
	17**
ICAO CAT I	9
ICAO CAT I & II	11
VS-modified	12

* For steady burning
** For flashers

With the FAA and ER Methods the optical axes of lights are aimed to intersect the glide slope at the designated distance as the glide slope is above the center of the flight-path envelope, the minimum beam spread is twice the maximum difference between the elevation of the optical axis and the elevation of the lower boundary of the flight-path envelope.

The ICAO beam spreads are listed in tables 2-1 and 2-2 of the Aerodrome Design Manual [20].

Since the optical axes of the lights are centered in the flight-path envelope by the VS method, the minimum beam spread for lights aimed in accord with this method is the maximum difference between the elevations of the upper and lower boundaries of the flight-path envelope at the designated distance.

3.3 Intensity Distribution Characteristics of Lights used in U.S. Approach-Light Systems

Detailed intensity distributions of the lights used in U.S. approach-light systems are given in Appendix IV. Table III is a summary of these data.

TABLE III

INTENSITY DISTRIBUTION CHARACTERISTICS OF U.S. APPROACH LIGHTS

Light Type	Representative Intensity (1) (Kilocandelas)	Horizontal Beam-Spread (2) (Degrees)	Vertical Beam-Spread (2) (Degrees)	Intensity Ratio I (3)	Intensity Ratio II (4)	Minimum Intensity (5) (Kilocandelas)	Maximum Intensity (5) (Kilocandelas)
150PAR38SP							
Sylvania	5.6	12	12	0.4	2.4	2.3	13.4
Westinghouse	5.7	16	14	0.4	1.5	2.5	8.7
GE-88	5.6	16	15	0.3	1.6	1.9	9.0
GE-64	6.0	16	16	0.5	1.5	2.8	9.0
Q20A/PAR56	28	37	12	0.7	1.2	18.6	33.1
FT34/HP	18	31	27	0.8	1.2	14.0	21.2

(1) See Appendix III for explanation of representative intensity.

(2) At 50% of peak intensity.

(3) Ratio of minimum intensity within the angular region specified in Table 5-1 of Annex 14 [21] for CAT I & II to the representative intensity.

(4) Ratio of peak intensity within the angular region specified in Table 5-1 of Annex 14 for CAT I & II to the representative intensity.

(5) Within angular region specified in Table 5-1 of Annex 14 for CAT I and II.

Table III indicates the following:

a) The representative intensity* of the PAR38 lamps is considerably less than that specified in table 5-1 of Annex 14, which requires that an approach light have 1.5 to 2.0 times the representative intensity of a high-intensity runway edge light, which is approximately 16 kilocandelas for the type L-819 light. Thus, the representative intensity of U.S. approach lights should be in the range of 24 to 32 kilocandelas.

b) The vertical beam spread of the PAR38 lamps is much greater than the minimum given in Annex 14 for CAT I approach lights, 9°.

c) The horizontal beam spread of the PAR38 lamps is much less than the minimum given in Annex 14, 20°, for CAT I approach lights.

d) Except for the General Electric lot 64 lamps, the ratio of minimum to representative intensity of the PAR38 lamps is less than that given in Annex 14, 0.5.

e) The ratio of peak to representative intensity of the Westinghouse PAR38 lamps is greater and that of the Sylvania lamps is much greater than that given in Annex 14, 1.5.

f) The PAR56 lamp meets all requirements listed in Annex 14 for CAT I, II, and III.

g) The beam spreads of the PAR56 lamp are considerably greater than those listed in Annex 14.

3.4 Evaluation of Several Methods of Determining Elevation-Setting Angles when Applies to U.S. Approach-Light Lamps

A comparison of the minimum vertical beam spreads given in Table II with the vertical beam spreads of the lamps given in Table III, only the vertical beam spread of the type FT34HP light is sufficient to meet the beam spread requirements of all methods of determining the elevation-setting angle.

Neither the PAR38 or the PAR56 incandescent lights meet the vertical beam spread requirements of the FAA or the ER-MALSR-200 methods.

Both the PAR38 and the PAR56 lights meet the vertical beam spread requirements of all other methods.

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* Appendix II contains an explanation of the meaning and application of the "representative intensity" and "effective intensity" concepts.

To facilitate a comparison of the effectiveness of the several methods of obtaining elevation-setting angles, tabulations were made of the intensities of the three types of approach-lights aimed by these methods toward a range of points within the flight-path envelope. These tabulations are given in Tables IV and VI.

The following factors should be considered in analyzing Tables IV and VI:

a) Differences in intensities of the order of 25% are not highly significant.

b) A decrease in intensity with increasing distance between the light and the selected point within the flight-path envelope (decrease in station number) is highly undesirable. *In particular, a sudden decrease in intensity with an increase in distance is to be avoided.*

c) A low intensity from the light nearest the selected point is beneficial as this tends to reduce glare.

d) An increase in intensity at a given station as the selected point goes from the upper boundary of the flight-path envelope through the glide slope to the lower boundary is far more desirable than the converse.

e) Since the beams of the lamps have no sharp peaks or valleys in their intensity distributions, longitudinal interpolation (between Stations and between distances from threshold) and vertical interpolation (between the upper boundary and the glide slope and between the glide slope and the lower boundary) is feasible.

Intensities for the Sylvania PAR38 lights and the flasher are given in table IV. The Sylvania PAR38 was selected for this analysis as its beam was sharper than the beams of the other PAR38 lamps, and hence, this type of lamp will be more sensitive to the effects of the different methods of determining elevation-setting angles than would the PAR38 lamps of the other manufacturers.

Inspection of this table shows, as stated earlier, that all methods are suitable for the FT34HP flasher. Table IVa shows the effects of the lamps not having sufficient vertical beam spread for the FAA and ER-MALSR-200 methods in that the intensities at the lower boundary of the flight-path envelope are lower than with the other methods. This effect is also shown in Tables IVb and IVc.

TABLE IV

INTENSITIES (IN KILOCANDELAS) DIRECTED TOWARD SELECTED POINTS IN THE FLIGHT-PATH ENVELOPE; 150PAR38/SP LAMP and FT/34 FLASHER

Table IVa. Distance of Aircraft from Threshold 7000'

Light at Station		Aiming Method: FAA	ER-MALSR-200	ER-MALSR-400	VS-200	VS-400
		150PAR38/SP (Sylvania)				
0 (1)	UB (2)	13	9	13	13	12
	GS	13	9	13	12	13
	LB	10	7	10	9	12
400	UB	13	10	13	13	12
	GS	12	9	13	12	13
	LB	9	7	10	9	11
1000	UB	12	10	13	13	11
	GS	10	9	13	12	12
	LB	8	7	10	9	11
1400	UB	12	11	13	13	11
	GS	10	10	13	12	12
	LB	8	7	10	9	11
		FT 34/HP (Flasher)				
1600	UB	17	18	17	17	17
	GS	18	18	17	17	17
	LB	17	17	17	18	17
2400	UB	17	17	17	17	17
	GS	18	18	17	17	17
	LB	17	17	17	18	17

LHA

Table IVb. Distance of Aircraft from Threshold 4000'

Light at Station		Aiming Method: FAA	ER-MALSR-200	ER-MALSR-400	VS-200	VS-400
		150PAR38/SP (Sylvania)				
0(1)	UB (2)	13	10	13	13	13
	GS	13	9	13	12	13
	LB	9	6	9	9	12
400	UB	13	11	12	13	13
	GS	12	10	13	13	13
	LB	9	6	10	9	11
1000	UB	13	13	11	12	12
	GS	11	10	13	13	12
	LB	8	6	10	9	11
1400	UB	13	13	8	10	12
	GS	11	11	12	13	12
	LB	7	7	10	9	11
		FT 34/HP (Flasher)				
1600	UB	17	17	17	17	17
	GS	17	18	17	17	17
	LB	17	16	17	17	17
2400	UB	17	17	16	17	17
	GS	17	17	17	17	17
	LB	16	17	18	17	17

Table IVc. Distance of Aircraft from Threshold 2000'

Light at Station		Aiming Method: FAA	ER-MALSR-200	ER-MALSR-400	VS-200	VS-400
		150PAR38/SP (Sylvania)				
0(1)	UB (2)	9	13	8	10	7
	GS	13	10	13	13	12
	LB	10	7	10	9	11
400	UB	7	11	6	7	5
	GS	13	11	13	13	11
	LB	9	7	10	9	11
800	UB	5	7	3	4	3
	GS	12	13	9	11	8
	LB	9	7	10	10	12
1000	UB	---- Cut off by cockpit ----				
	GS	11	13	7	9	6
	LB	9	8	11	10	12
1400	UB	---- Cut off by cockpit ----				
	GS	5	5	3	3	3
	LB	9	8	13	11	13
		FT 34/HP Lamp (Flasher)				
1600	UB	---- Cut off by cockpit ----				
	GS	---- Cut off by cockpit ----				
	LB	17	18	17	17	17

NOTES:
(1) Intensities of threshold lights are for unfiltered lights. Multiply by 0.2 to obtain intensities in green.
(2) UB - Aircraft at upper boundary of the flight-path envelope.
GS - Aircraft on glide slope.
LB - Aircraft on lower boundary of flight-path envelope.

The table indicates that the ER-400, the VS-200 and the VS-400 methods will provide satisfactory coverage for decision heights in the range of 200 to 400 feet. At 7000 feet from the threshold, the entire vertical section of the flight-path envelope through the extended runway centerline is covered by the center of the light beam. As an even smaller portion of the light beam, which lies within the portion required for a distance of 7000 feet, all distances greater than 7000 feet will be adequately covered by lights aimed by methods ER-MALSR-400, VS-200, and VS-400. Table IV indicates no clear advantage for any one of these three methods. However, there is a consistent, though minor, higher intensity at the lower boundary of the flight-path envelope when the VS-400 method is used. Therefore, this method is recommended for determining the elevation-setting angles of the 150PAR38/SP lights in the MALSR approach-light system for decision heights of 200 feet and more. An elevation setting angle of 6^{o} is recommended for the flashers. This choice is very arbitrary. It is based upon the expectation that a flasher which concentrates light more effectively into the desired beam dimensions will be used in the future.

The recommended angular settings for each station of the MALSR approach-light system are given in Table V.

TABLE V

PROPOSED ELEVATION-SETTING ANGLES FOR MALSR APPROACH LIGHTS

Station		Setting Angle (Degrees)
	150PAR38/SP	
0		3.1
200		3.2
400		3.3
600		3.4
800		3.4
1000		3.5
1200		3.6
1400		3.7
	Flashers	

The elevation-setting angle for all stations is 6.0 degrees.

Intensities for the Q20A/PAR56 lamp are tabulated in Table VI.

TABLE VI

INTENSITIES (IN KILOCANDELAS) DIRECTED TOWARD SELECTED POINTS
IN THE FLIGHT-PATH ENVELOPE; Q20A/PAR56 LAMP

Table VIa. Distance of Aircraft from Threshold 4000 ft.

Light at Station		Aiming Method: FAA	ER ALSF-2	VS-200	VS-Modified
0(1)	UB(2)	33	32/33(3)	33	32
	GS	33	33/30	32	30
	LB	26	27/17	22	18
400	UB	33	8	33	33
	GS	32	4	33	31
	LB	21	1(4)	22	17
900	UB	33	13	32	33
	GS	31	5	33	31
	LB	16	1(4)	21	16
1000	UB	33	28	31	28
	GS	31	20	33	32
	LB	16	4	21	16
1400	UB	33	31	30	32
	GS	31	23	33	32
	LB	13	4	21	15
1600	UB	32	33	29	31
	GS	31	25	32	33
	LB	11	4	21	15
2000	UB	30	33	25	30
	GS	32	29	33	33
	LB	9	4	21	14
2400	UB	27	28	15	30
	GS	33	33	30	32
	LB	8	5	21	14
3000	UB	----- Cut off by cockpit -----			
	GS	26	26	11	17
	LB	7	7	22	16

LHA

Table VIb. Distance of Aircraft from Threshold 2000 ft.

Light at Station		Aiming Method: FAA	ER ALSF-2	VS-200	VS-Modified
0(1)	UB(2)	28	28/31(3)	30	31
	GS	33	33/31	33	32
	LB	26	28/19	27	25
400	UB	24	26	25	28
	GS	33	7	33	33
	LB	24	1(4)	28	25
900	UB	11	33	17	12
	GS	32	17	30	32
	LB	22	1(4)	28	25
1000	UB	----- Cut off by cockpit -----			
	GS	31	32	28	31
	LB	22	7	29	25
1400	UB	----- Cut off by cockpit -----			
	GS	15	26	7	13
	LB	24	11	32	28
1600	UB	----- Cut off by cockpit -----			
	GS	----- Cut off by cockpit -----			
	LB	29	20	33	31

Table VIc. Distance of Aircraft from Threshold 1000 ft.

Light at Station		Aiming Method: FAA	ER ALSF-2	VS-200	VS-Modified
0(1)	UB(2)(5)	26	9/19(3)	28	30
	GS	33	22/29	33	33
	LB	31	31/33	30	29
200	UB	21	30	20	25
	GS	31	19	31	32
	LB	31	3	31	30
400	UB	7	33	6	14
	GS	29	28	26	28
	LB	33	4	33	31
600	UB	----- Cut off by cockpit -----			
	GS	13	33	7	16
	LB	33	11	32	33
800	UB	----- Cut off by cockpit -----			
	GS	----- Cut off by cockpit -----			
	LB	----- Cut off by cockpit -----			

NOTES: (1) Intensities of threshold lights are for unfiltered lights. Multiply by 0.2 to obtain intensities in green.
(2) UB - Aircraft at upper boundary of flight-path envelope.
GS - Aircraft on glide slope.
LB - Aircraft on lower boundary of flight-path envelope.
(3) For alternate lights.
(4) Extrapolated value.
(5) Table VIc based upon CAT II flight-path envelope.

Table VIa indicates immediately that the ER-ALSF2 is unsatisfactory in that the intensities of the lights at Stations 4 through 9 directed toward the glide path are much too low because of the high elevation setting of these lights, 13.8°. Tables VIb and VIc also show this effect to a lesser extent. The effect would be greater at distances greater than 4000 feet from threshold.

The intensities of lights aimed according to the FAA method are low for a position on the lower boundary of the flight-path envelope - 4000 feet from threshold, particularly for the outermost lights, which is highly undesirable, and for positions on the upper boundary of the CAT II flight-path envelope.

The VS-modified method provides better coverage at the upper boundary of the CAT II flight-path envelope, as shown in table VIc (as well as for positions on the glide path for CAT III operations), at the expense of a reduction in intensities directed at positions on the lower boundary at distances of 4000 feet and more from threshold.

The use of the VS-modified method of obtaining the elevation-setting angles for the Q20A/PAR56 light in the ALSF-2 approach-light system is recommended. Elevation-setting angles for light stations in this system are given in Table VII.

TABLE VII

PROPOSED ELEVATION-SETTING ANGLES
FOR Q20A/PAR56 APPROACH-LIGHT LAMPS

Station	Setting Angle (Degrees)	Station	Setting Angle (Degrees)
3000	8.0	1400	7.0
2900	7.9	1300	6.9
2800	7.9	1200	6.9
2700	7.8	1100	6.8
2600	7.7	1000	6.7
2500	7.7	900	6.7
2400	7.6	800	6.6
2300	7.6	700	6.5
2200	7.5	600	6.5
2100	7.4	500	6.4
2000	7.4	400	6.3
1900	7.3	300	6.3
1800	7.2	200	6.2
1700	7.2	100	6.2
1600	7.1	0	6.1
1500	7.0		

4. DISCUSSION

4.1 Methods of Aiming

4.1.1 Flashers

The vertical beam spread of the flashers meeting the requirements of specifications FAA-1106 and FAA-1250 is so large that their performance will be satisfactory when aimed by any of the methods discussed. Using an elevation-setting angle of 6° at all stations for the present flashers is recommended.

4.1.2 Incandescent Lights in the ALSF-2 Approach-Light System

The present method of aiming the lights of high-intensity approach-light systems (the FAA method) aims the lights so that their optical axes intersect the glide slope 1600 feet ahead of the light. This method does not provide adequate coverage at the lower boundary of the flight-path envelope because of the large elevation-setting angles required for the outermost lights of the system, and, at the same time, the elevation of the innermost lights is not sufficient to cover the upper boundary of the Category II flight-path envelope.

The aiming method proposed for the ALSF-2 in the Engineering Requirements for this Study also aims the beams at too great an elevation.

The Visual Segment-Modified method is designed to provide the optimum coverage of the flight-path envelope by the type Q20A/PAR56 lamp used in the system. Use of the elevation setting angles listed in Table VII is recommended.

4.1.3 Incandescent Lights in the MALSR Approach-Light System

Performance of the type 150PAR38/SP lamps in the MALSR approach-light system will be improved, particularly for operations with decision heights greater than 200 feet by the use of the method of aiming proposed in the Engineering Requirements for this Study or by the Visual Segment Method. The elevation-setting angles given in Table V are recommended for use with the type 150PAR38/SP lamp for decision heights of 200 feet and more.

Although use of the recommended method of aiming will improve the performance of the MALSR system, the improvement is not expected to overcome the criticisms which have been made of the MALSR system.

4.2 Light Characteristics

Although a study of the intensity distribution characteristics was not called for in the Engineering Requirements for this Study, several factors which should be considered became evident during the study. These are discussed below.

4.2.1 Flashers

The vertical beam spread of the flashers meeting the requirements of specifications FAA-1106 and FAA-1250 is much larger than necessary. Use of a light with a vertical beam spread of about 12° could result in considerable savings in energy consumption.

4.2.2 Type Q20A/PAR56 Lamp

This lamp is designed to have a horizontal beam spread of 30°, whereas the requirements given in Table 5-9 of Annex 14 [21] are a horizontal beam spread of 20°.

High-intensity approach-light systems used in the U.S. have had 30° horizontal beam spreads since the introduction of PAR-type lamps into these systems (circa 1950). If the 30° horizontal beam spread is no longer needed, a reduction of about 30% in energy consumption could be obtained by the use of lamps having 20° horizontal beam spreads while maintaining the present representative intensity and vertical beam spread.

4.2.3 Type 150PAR38/SP Lamp

This type of lamp is one of the very few lamps used in aviation ground lighting which was not designed for its particular application, but was "taken off the shelf." It meets few of the intensity distribution requirements set forth in ICAO documents. Its primary defect is a lack of sufficient horizontal beam spread with the result that the intensities directed toward the lateral boundaries of the flight-path envelope are too low to be effective in daylight operations. For example, an intensity of 5 kilocandelas is required to provide a visual range equal to the meteorological visibility when the meteorological visibility is one-half mile and an intensity of 20 kilocandelas is required when the meteorological visibility is one mile. Thus, these lamps provide little additional guidance in daylight conditions over a considerable part of the flight-path envelope.

The lamp is an inefficient generator of an approach-light beam as shown in Table VIII. In considering this table, it should be remembered that the PAR38 lamp is a 150-watt lamp and the PAR56 lamp is a 300-watt lamp.

Development of a lamp having intensity distribution characteristics appropriate for the MALS system is urgent.

TABLE VIII

APPROACH-LIGHT LAMP INTENSITIES (IN KILOCANDELAS) AT SELECTED ANGLES

Angles (Degrees) H	V	Sylvania PAR38(1)	Westinghouse PAR38(1)	General Electric PAR38(1) Lot 64	General Electric PAR38(1) Lot 88	PAR56
0	0	13.4	8.7	9.4	9.0	33.1
0	3	9.6	7.6	8.2	6.6	29.4
0	-3	10.2	7.6	7.7	7.2	28.7
0	5	6.9	6.0	6.7	4.6	24.7
0	-5	8.7	6.1	6.4	6.9	21.1
3	0	9.6	8.0	8.6	8.0	32.5
-3	0	9.5	7.8	7.9	7.7	32.9
5	0	8.0	6.0	7.5	6.9	31.9
-5	0	7.3	6.4	6.5	6.2	32.5
10	0	3.6	3.8	3.8	3.6	29.7
-10	0	2.6	2.7	3.4	2.6	31.0
15	0	NA(2)	1.7	1.3	1.4	24.9
-15	0	NA	1.3	1.2	1.1	27.9

Angles (Degrees) H	V	Sylvania PAR38(1)	Westinghouse PAR38(1)	General Electric PAR38(1) Lot 66	General Electric PAR38(1) Lot 88	PAR56
5	3	6.9	6.0	6.5	5.1	28.6
5	-3	8.1	6.1	6.8	7.4	28.4
-5	3	6.3	5.8	5.6	4.3	28.9
-5	-3	7.2	5.6	5.3	7.1	28.2
10	3	2.9	3.4	3.4	2.8	26.6
10	-3	3.5	3.4	3.5	3.8	27.0
-10	3	2.3	2.6	2.8	1.9	27.2
-10	-3	2.6	2.5	3.4	3.2	26.5
10	4	2.6	3.1	3.1	2.5	24.4
10	-4	3.4	3.2	3.2	3.8	24.3
-10	4	2.2	2.5	2.3	1.7	25.6
-10	-4	2.5	2.3	3.3	3.3	22.7
10	5	2.4	2.8	2.9	2.2	24.4
10	-5	3.1	2.9	3.0	3.8	24.3
-10	5	2.1	2.4	2.0	1.6	23.4
-10	-5	2.4	2.2	3.1	3.3	17.6
15	5	NA(2)	1.5	1.1	1.0	16.2
15	-5	NA	1.4	1.2	1.2	15.0
-15	5	NA	1.2	0.9	1.0	20.0
-15	-5	NA	1.2	1.2	1.2	13.8

(1) Average of three lamps.
(2) NA - Not available.

The intensity of threshold lights is of particular concern. When green filters are added to the type 150PAR38/SP lamps, the intensities are reduced to about 20% of the intensities of the unfiltered lamps. Since the representative intensity of the unfiltered PAR38 lamps is less than 6 kilocandelas, the representative intensity of the threshold lights using these lamps will be less than 1.2 kilocandelas, an intensity which is unsatisfactory, especially during daylight. If the type L802 or L861E lights are used for threshold lights, the situation is even worse as the representative intensity (in green) of these lights is about 0.5 kilocandelas. Threshold lights having representative intensities (in green) of 5 kilocandelas or more are urgently needed.

4.3 Aiming of Semiflush Approach Lights

Semiflush approach lights are required when the approach-light system extends into a displaced threshold or paved overrun area. Use of the elevation-setting angles obtained by using the VS-Modified method, listed in table VII, is usually impracticable for the following reasons:

a) The difficulty of providing for a different elevation-setting angle for each station at which these lights are to be used.

b) The vertical beam spread of semiflush approach lights is less than the vertical beam spread of the Q20A/PAR56 approach-light lamps, particularly at the lateral boundaries of the flight-path envelope.

These lights should provide coverage for both Category I and Category II operations. Computations using the VS method show that the beam of a light at station 100 should extend from 0.5° to 10.2°, and for a light at station 900 the beam should extend from 0.6° to 13.1°. The corresponding elevation-setting angles would then be 5.4° and 6.8°, and the corresponding vertical beam-spread requirements would be 9.7° and 12.5° at 50% of peak intensity.

In considering these angles, the following factors should be noted:

a) It is not practicable to provide an intensity equal to 50% of the peak intensity at an elevation of 0.6° at the lateral boundaries of the flight-path envelope. An elevation of 1.5° is a more reasonable goal for the lower boundary of the region to be covered by a semiflush approach-light.

b) Specification FAA-E-2491 presently requires that semiflush approach lights provide an intensity of at least 10 kilocandelas throughout a region extending from an elevation of 2° to an elevation of 12°. Because of the vertical asymmetry in the beams of simiflush approach lights caused by mechanical shielding at elevations less than about 2°, the elevation of the beam axis of a light meeting this requirement will be about 8°.

c) The elevation of the line of sight from a light at station 100 to an aircraft on the glide slope and 1200 feet from the light is 8.2°. For a light at station 900 the corresponding elevation is 10.2°.

Considerations of the factors listed above indicates that no change in the intensity distribution requirements of specification FAA-E-2491 for semiflush approach lights.

5. CONCLUSIONS

A method of determining the elevation-setting angles for approach lights based upon fundamental principles has been developed. This method considers the effects of the applicable decision height, the required visual range, the glide slope, the distance of the light from the threshold, and the vertical beam spread of the light.

This method, defined as the Visual Segment method, has been compared with other methods and found to be preferable.

Elevation-setting angles have been computed for the lights of the MALSR and ALSF-2 approach-light systems when lamped with the types of lamps presently in service.

The suitability of the intensity distribution characteristics of the lights currently used in U.S. approach-light systems has been analyzed and possible changes noted.

6. RECOMMENDATIONS

It is recommended that:

1. The elevation-setting angles listed in Table V be used for the MALSR approach-light system when lamped with type 150PAR38/SP lamps and type FT34/HP or CD-100 flashers.

2. The elevation-setting angles listed in Table VII be used for the ALSF-2 system lamped with type Q20A/PAR56 lamps and that an elevation-setting angle of 6° be used for the type FT34/HP and type CD-100 flashers of this system.

3. No change be made in the intensity distribution requirements for semiflush approach lights in specification FAA-E-2491.

4. The principles outlined for the Visual Segment method of determining elevation-setting angles be used in determining these angles when new types of lamps are introduced.

5. Efforts be made to obtain flashers with vertical beam spreads of the order of 12° instead of the 25° vertical beam spread of present flashers.

6. A study be made to determine if a 30° horizontal beam spread is still required of approach lights. If this beam spread is no longer required, lights having the necessary (narrower) horizontal beam spread should be developed.

7. A light having intensity distribution characteristics suitable for the MALS approach-light system be developed as a replacement for the type 150PAR38/SP lamps.

8. Develop a threshold light for the MALS approach-light system which will have a representative intensity (in green) of at least 5 kilocandelas.

APPENDIX I

CRITERIA FOR JUDGING UNIFORMITY OF INTENSITY

One of the criteria by which the suitability of the intensity distribution of an approach light is judged is its uniformity of intensity within the defined angular subtense. This Appendix gives criteria by which uniformity of intensity may be judged.

Although the human eye can detect differences in contrast between an object and its background (for example, a stack against the sky) of the order of a few percent, it is much less sensitive to differences in the illumination from point sources. (The ratio of the illuminances of the two sources is equal to the ratio of intensities if observing conditions for the two lights are the same. Hence, in this report, ratios of intensities will be considered.)

The author's experience indicates that an experienced observer, working under ideal conditions, cannot match the intensities of adjacent light sources to closer than about 10 percent. Balder, in a study of "Light intensity tolerances in a row of runway lights" [a], found that deviations in light intensity between 0.7 and 1.3 times the nominal intensity in a row were not noticed in more than 90% of the observations and that deviations between 0.6 and 1.5 times the nominal intensity were "completely unnoticed" in more than 75% of the observations. The ratios between high and low intensities in these two cases are 1.9 and 2.5, respectively. In the NBS approach-light tests at Nantucket, Breckenridge and Douglas found that a ratio between intensities of four was sufficient to cause the appearance of the lights to be described by a different rating term [2]. In 1966, the Visual Aids Panel using such data established the requirement that the minimum intensity in the defined beam should be not less than 0.5 of the "average" intensity and that the peak intensity should be not greater than 1.5 times the average intensity [16]. A consequential criterion is that the ratio *of peak to minimum intensity within the specified angular subtense of the beam should* be not greater than three. The criteria have been used in ICAO pertinent documents since that time [17, 20, 21].

Thus, a ratio as great as three to one between the maximum and minimum intensities within the specified beam dimensions is considered acceptable. A ratio of less than two to one is desirable.

APPENDIX II

REPRESENTATIVE, OR "AVERAGE" INTENSITY AND EFFECTIVE INTENSITY

This Appendix contains an explanation of the origin and application of the concept of representative intensity, designated as 'average' intensity by ICAO, and of effective intensity.

II-1 Representative Intensity

The concept of using a representative intensity in computing the effective visual range of airfield lights originated in the U.S. during the early development of the runway visual-range program [b].

Its application is explained in the following quotation:

> "The selection of an intensity representative of an approach or runway light is at best a somewhat arbitrary procedure. In the past the maximum intensity of the light has been used frequently. This is unsatisfactory since the probability that a pilot will be precisely in the peak of the beam is very low. - - -
>
> To avoid undue influence on the representative intensity which would be produced by a narrow peak having an intensity much greater than other parts of the beam in the determination of representative intensity, all intensities more than three times the minimum intensity within the region are treated as being three times the minimum." [c]

This concept was adopted in 1966 at the Fifth Meeting of the Visual Aids Panel [d] and has been used in pertinent ICAO documents since that time [17, 20, 21].

An example of the application of the representative intensity concept is given in the evaluation of the 250-watt, narrow-beam PAR56 lamp, referred to in Section 2.5. Although the peak intensity of this lamp was 80 kilocandelas, its representative intensity was only 4 kilocandelas [c]. The flashers have a representative intensity of about 15 kilocandelas were often seen a *significant distance farther* than the 250-watt lamp, an occurrence often attributed at the time to some peculiar advantage of the flashers

in fog penetration when it was, in fact, caused by misusing the peak intensity as a characterization of the lamp [14, 26, e page 265].

II-2 Effective Intensity

The intensities used in characterizing flashing lights are effective intensities computed by methods agreed upon by ICAO and used in the U.S. for evaluating signal lights [e page 264, f].

For short flashes, such as those emitted by the approach-light flashers, this effective intensity is given by

$$I_e = 5 \int_0^t I dt,$$

where

I_e is the effective intensity, and

I is the instantaneous intensity at any time during the flash.

The instantaneous intensity is integrated over the entire flash.

APPENDIX III

DERIVATIONS AND COMPUTATIONS

III-1 Angles of View of a Light at Selected Points within the ICAO Flight-Path Envelope

This Section consists of the development of the equations used to compute the angle at which an approach light at station S is viewed from an aircraft a distance d from the threshold and on the glide slope or the upper or lower boundaries of the ICAO CAT I and CAT II flight-path envelopes shown in figure 5-9 of reference 8.

Symbols used are as follows:

l	=	length of area cut off by cockpit
S	=	station of light; distance of light from the threshold
V	=	length of the visual segment
d	=	distance of aircraft from the threshold
h	=	height of aircraft above the threshold
Δh	=	displacement of light from the horizontal plane passing through the threshold
α	=	Elevation of the line of sight of a light when the aircraft is on upper boundary of the flight-path envelope
β	=	elevation of the line of sight of a light when the aircraft is on the lower boundary of the flight-path envelope
γ	=	elevation of the line of sight aircraft on glide slope
ϕ	=	the elevation-setting angle of the optical axis of the light
ϕ'	=	elevation-setting angle corrected for displacement of light

ϕ'' = elevation setting angle corrected for displacement of light by approximate method

σ = cockpit cutoff angle

θ = glide slope

Δ = vertical beam spread of light

ψ = slope of upper boundary of flight-path envelope

Figures are not to scale.

III-1.1 Aircraft on Glide Slope

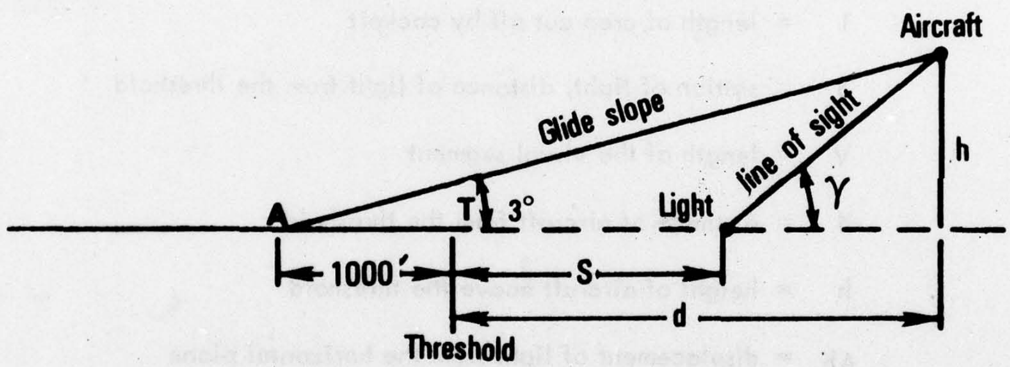

Figure III-1. Geometric Relations, Aircraft on Glide Slope

From Figure III-1,

$$\gamma = \tan^{-1} h/(d-S), \tag{III-1}$$

and

$$h = (d + 1000) \tan 3^{\circ}, \tag{III-2}$$

combining terms,

$$\gamma = \tan^{-1} (d + 1000) \tan 3^{\circ}/(d-S). \tag{III-3}$$

III-1.2 Aircraft on Upper Boundary of Flight Path Envelope

III-1.2.1 Category I operations

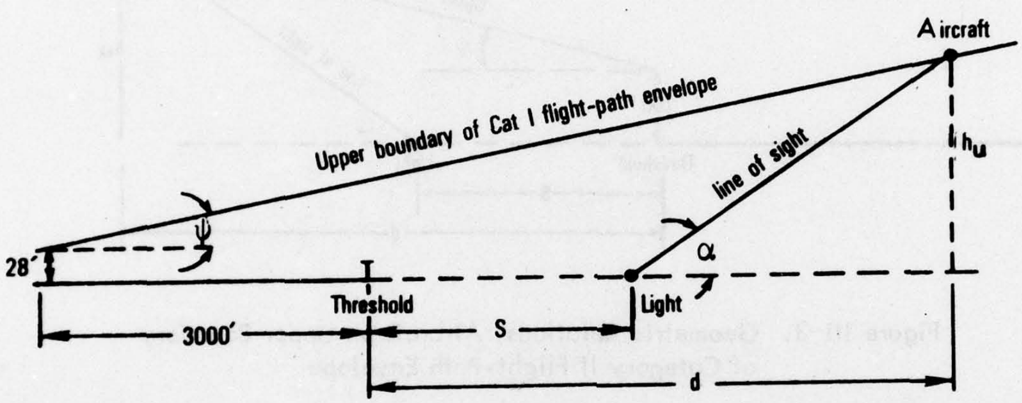

Figure III-2. Geometric Relations, Aircraft on Upper Boundary of Category I Flight-Path Envelope (See Figure 3 for details of boundaries of ICAO flight-path envelopes)

From Figure III-2,

$$h = (d + 3000) \tan \psi + 28. \qquad \text{(III-4)}$$

From Figure 5-9 of Annex 14,

$$\tan \psi = (524-28)/(3000 + 3000 + 3666)$$

or

$$\tan \psi = 0.05131. \qquad \text{(III-5)}$$

Combining equations III-1, III-4, and III-5;

$$\alpha = \tan^{-1} [((d + 3000)(0.05131) + 28)/(d-S)] \qquad \text{(III-6)}$$

for CAT I operations.

III-1.2.2 Category II Operations

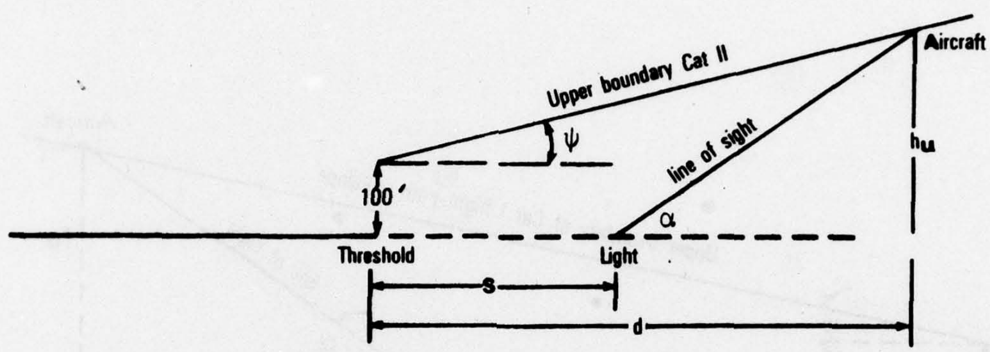

Figure III-3. Geometric Relations, Aircraft on Upper Boundary of Category II Flight-Path Envelope

From Figure III-3,

$$h = 100 + d \tan\psi. \qquad \text{(III-7)}$$

From Figure 5-9 of Annex 14,

$$\tan\psi = (488-100)/(3000+3666),$$

or

$$\tan\psi = 0.0582. \qquad \text{(III-8)}$$

Combining equations III-1, III-7, and III-8,

$$\alpha = \tan^{-1} [(100 + 0.0582\, d)/(d-S)]. \qquad \text{(III-9)}$$

III-1.3 Aircraft on Lower Boundary of Flight-Path Envelope

III-1.3.1 Category I Operations

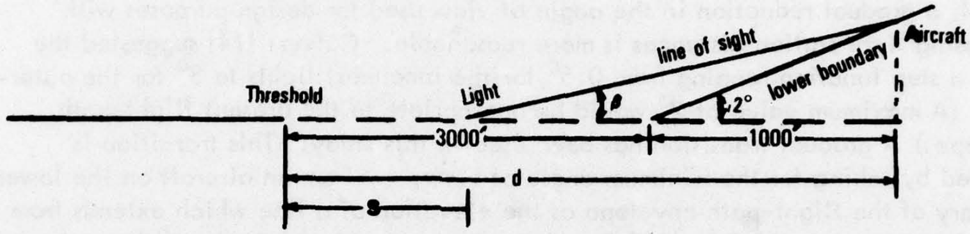

Figure III-4. Geometric Relations, Aircraft on Lower Boundary of Category I Flight-Path Envelope; Aircraft 3000 feet or more from Threshold

From Figure III-4,

$$\beta = \tan^{-1} h/(d-S), \qquad \text{(III-10)}$$

and

$$h = (d-3000) \tan 2^{\circ}. \qquad \text{(III-11)}$$

Combining equations III-10 and III-11,

$$\beta = \tan^{-1} [(d-3000) \tan 2^{\circ}/(d-S)]. \qquad \text{(III-12)}$$

Equation III-12 and figure III-4 show that β *is* 2° *for a light at station 3000* independent of the distance, d, of the aircraft from the threshold. However, for all stations less than 2900 the value of β approaches 2° when d is large and approaches 0° when d approaches 3000 feet. Moreover, equation III-12 is not applicable when the aircraft is less than 3000 feet from the threshold. Thus, equation III-12 does not provide a satisfactory value of β for lights at stations 2900 and lower.

Inspection of Figure 5-9 of Annex 14 does not yield a clear methodology of determining the angle of view when the aircraft is on the lower boundary of the CAT I flight-path envelope and the light is less than 3000 feet from the threshold. A strict interpretation of the figure indicates that the angle of view of the lights between the aircraft on the boundary and the threshold is zero when the light is less than 3000 feet from the threshold. Thus, the angle of view of a light at station 2900 would be 0°. However, the angle of view for a light at station 3000 is 2° for all distances greater than 3000 feet. This sudden change in angles of view is not logical; a gradual reduction in the angle of view used for design purposes with decreasing light station distances is more reasonable. Calvert [14] suggested the use of a step function ranging from 0.5° for the innermost lights to 3° for the outermost. (A maximum value of 2° would be appropriate to the present flight-path envelope.) A gradual transition has been used in this study. This transition is obtained by taking for the minimum angle of view, β, from an aircraft on the lower boundary of the flight-path envelope as the elevation of a line which extends from the light to a point which is 4000 feet from the threshold and on the 2° lower boundary of Figure 5-9, as shown in Figure III-5.

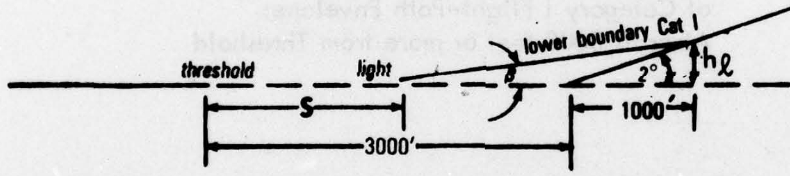

Figure III-5. Geometric Relations, Aircraft on Lower Boundary of Category I Flight-Path Envelope; Aircraft less than 3000 feet from Threshold

From Figure III-5,

$$h = 1000 \tan 2^\circ, \tag{III-13}$$

and

$$\beta = \tan^{-1} [1000 \tan 2^\circ/(3000 - S + 1000)] \tag{III-14}$$

or

$$\beta = \tan^{-1} [34.9/(4000 - S)]. \tag{III-15}$$

This procedure provides a continuous function of β with values ranging from 0.5° for a light at the threshold to 1.8° for a light at station 2900.

III-1.3.2 Category II operations

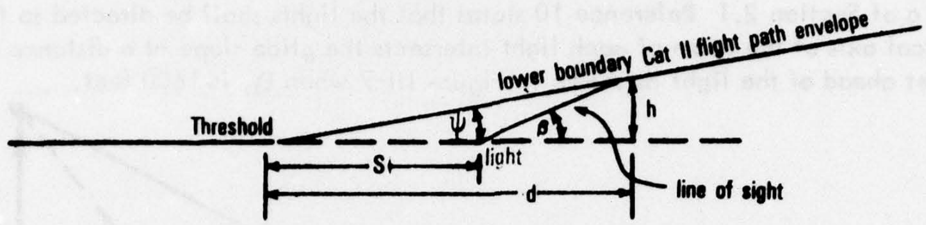

Figure III-6. Geometric Relations, Aircraft on Lower Boundary of Category II Flight-Path Envelope

From Figure III-6,

$$h = d \tan \psi. \tag{III-16}$$

From Figure 5-9 of Annex 14,

$$\tan \psi = 315/(3000 + 3666),$$

or

$$\tan \psi = 0.0472. \tag{III-17}$$

Combining equations III-10, III-16 and III-17,

$$\beta = \tan^{-1} [0.0472\, d/(d - S)]. \tag{III-18}$$

When d is very large, β approaches a minimum value of $\tan^{-1} 0.0472$ or 2.7°.

III-2 Methods of Determining the Elevation-Setting Angle

III-2.1 By FAA Method

The method of determining the elevation-setting angle of approach lights is Method a of Section 2.1 Reference 10 states that the lights shall be directed so that the optical axis of the beam of each light intersects the glide slope at a distance of 1600 feet ahead of the light as shown in Figure III-7 when D_o is 1600 feet.

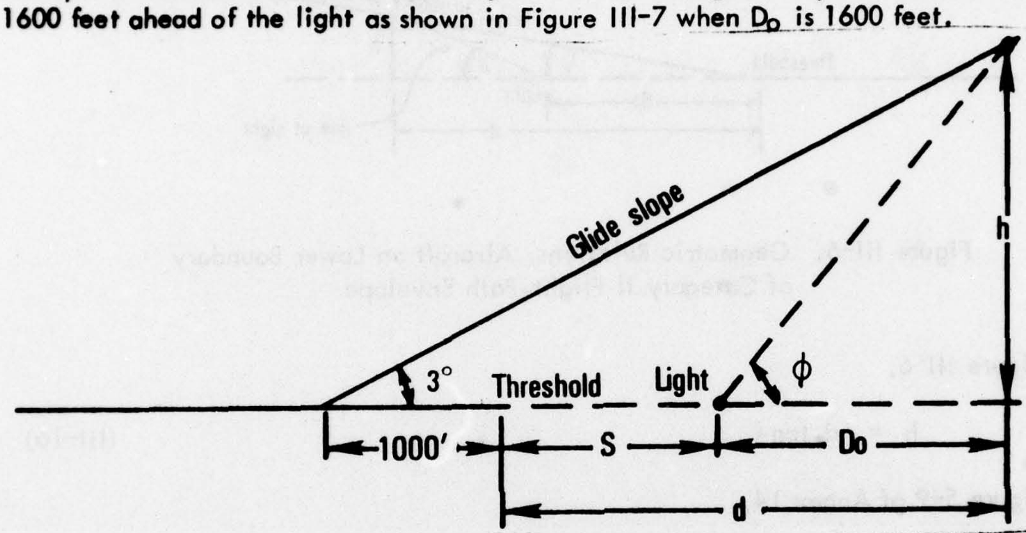

Figure III-7. Geometric Relations Used in Computing Elevation-Setting Angles by the FAA and ER Methods

From Figure III-7

$$\phi = \tan^{-1} (h/D_o), \tag{III-19}$$

$$h = (D_o + S + 1000) \tan 3^{\circ}, \tag{III-20}$$

and

$$D_o = 1600. \tag{III-21}$$

Combining terms

$$\phi = \tan^{-1} [(1600 + S + 1000) \tan 3^{\circ}/1600],$$

or

$$\phi = \tan^{-1} [(2600 + S) \tan 3^{\circ}/1600]. \tag{III-22}$$

III-2.2 By ER Method

The method proposed in the Engineering Requirement for this report consists of aiming specified lights of a group in the system so that the optical axis of each of these lights intersects the glide slope at the decision height and then elevating other lights of the group to the same angle. (See Section 1.3.6)

For the specified lights, referring to Figure III-7, the height h with this method is H, the decision height. Equation III-20 may be solved for D_o. Thus,

$$D_o = (H/\tan 3^o) - S - 1000, \tag{III-23}$$

and combining equations III-19 and III-23

$$\phi = \tan^{-1} [H/((H/\tan 3^o) - S - 1000)] \tag{III-24}$$

III-2.3 By the VS Method

The VS (Visual Segment) method consists of determining the designated distance, D_o, which will provide a visual segment of specified length, V, at the DH, computing the elevations of points on the upper and lower boundaries of the flight path envelope, α and β, respectively, at the designated distance from a light; and computing the elevation-setting angle as the mean of these two angles.

III-2.3.1 Computation of Designated Distance

If the approach-light system extends beyond the point where cockpit cutoff line intersects the horizontal plane through the threshold (point Q of Figure 1, the designated distance is

$$D_o = V + I,$$

or

$$D_o = V + H/\tan \sigma . \tag{2d}$$

The generally accepted value of σ, the cockpit cutoff angle, for design purposes is 15 degrees* and of the visual segment is 500 feet* [17]. See Figure III-8.

* These values were used by the author in the preparation of Table 5-1 of Annex 14, Seventh Edition [21], and of Table 2-1 of the Aerodrome Design Manual, First Edition [20], but no formal reference to their use could be found in ICAO documents.

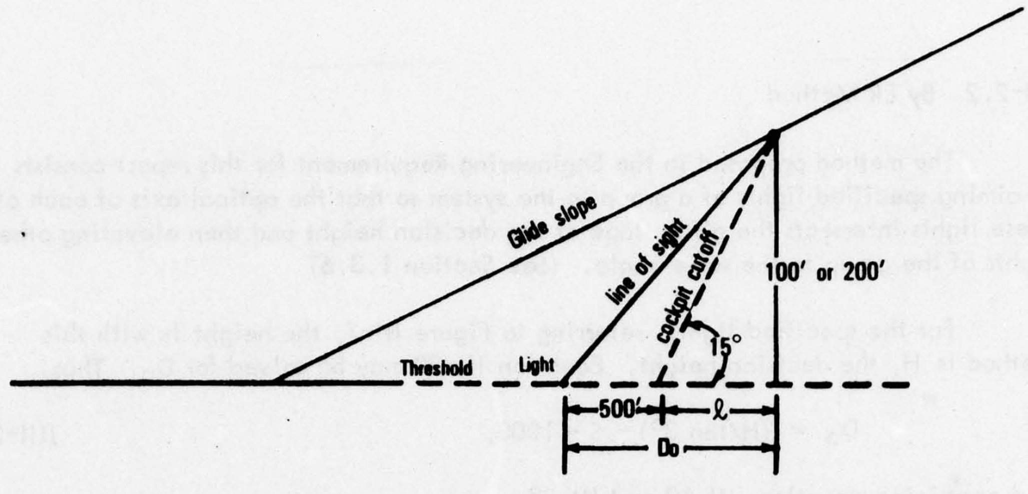

Figure III-8. Geometric Relations Used in Computing the Designated Distance for the VS Method when the Approach-Light System Extends to the Cockpit Cutoff at the Decision Height

Therefore

$$D_o = 500 + H/\tan 15^o \qquad \text{(III-25)}$$

or

$$D_o = 1246$$

for Category I operations, and

$$D_o = 873$$

for Category II operations.

When the approach light system does not extend to the cockpit cutoff, the geometry is that shown in Figure III-9.

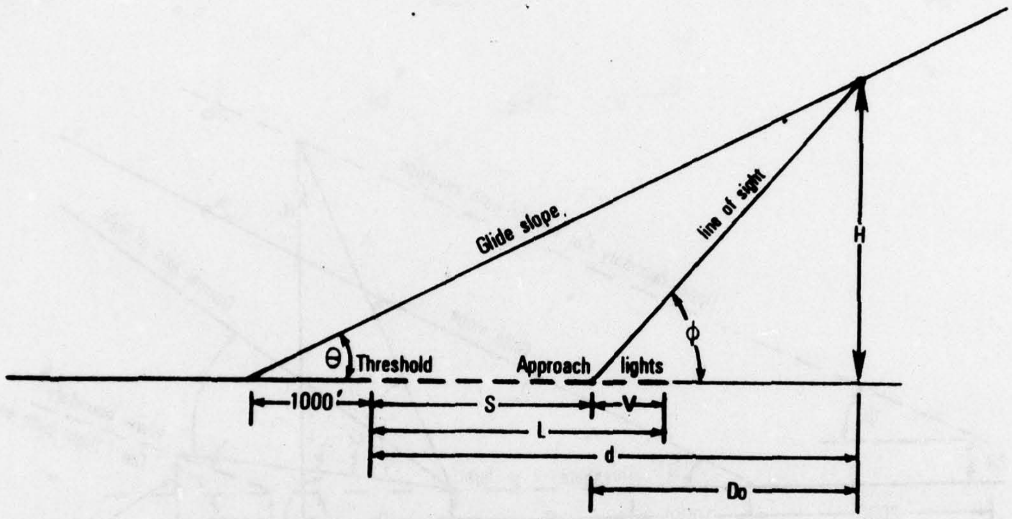

Figure III-9. Geometric Relations Used in Computing the Designated Distance for the VS Method when the Approach-Light System does not Extend to the Cockpit Cutoff

From this Figure, it is evident that

$$d = H/\tan \theta - 1000,$$

and

$$D_o = d - L + V, \qquad \text{(III-26)}$$

or, combining terms and inserting the values of θ (3^o), of V (500) and of L (2400)

$$D_o = (H/\tan 3^o) - 2900. \qquad \text{(III-27)}$$

The values of D_o for decision heights of 300, 400, and 500 feet are 2824, 4732, and 6640 feet, respectively.

III-2.3.2 Computation of Upper and Lower Limits of the Beam

The elevation of the line of sight to the upper boundary of the CAT I flight-path envelope can then be computed from equation III-6 by using the appropriate value of D_o and the relation

$$d = D_o + S. \quad \text{(See Figure III-10)} \qquad \text{(III-28)}$$

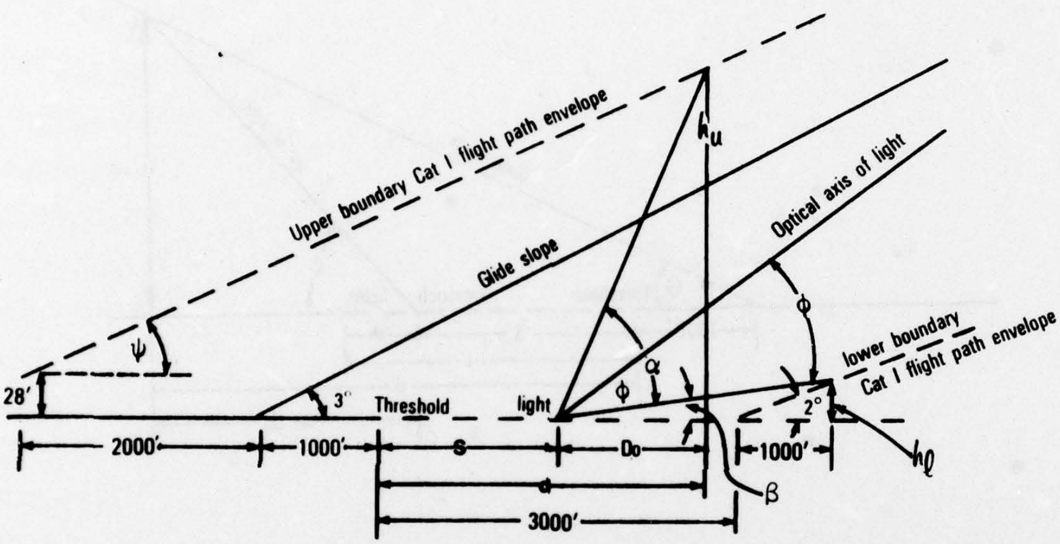

Figure III-10. Basic Geometric Relations Used in Computing Elevation-Setting Angles by the VS Method

Thus, from equation III-6,

$$\alpha = \tan^{-1} [(28 + (3000 + S + D_o) \times 0.05131)/D_o]. \qquad \text{(III-29)}$$

Also, from equation III-15,

$$\beta = \tan^{-1} [34.9/(4000 - S)]. \qquad \text{(III-30)}$$

The elevation-setting angle is then

$$\phi = (\alpha + \beta)/2 \qquad \text{(III-31)}$$

and the required beam spread is

$$\Delta = \alpha - \beta . \qquad \text{(III-32)}$$

Similarly for CAT II operations, the elevation of the line of sight to the upper boundary of the CAT II flight-path envelope is obtained by means of equation III-9, thus

$$\alpha = \tan^{-1} [(100 + 0.0582 (D_o + S))/D_o] . \qquad \text{(III-33)}$$

From equation III-18, the minimum value of β is 2.7^o. Since this value is greater than any value of β obtained from equation III-30, the latter values of β were used in computing the elevation-setting angles.

III-3 Correction of Elevation-Setting Angle for Displacement of Light from Horizontal Plane Passing through the Threshold

A correction may be required in the elevation-setting angle of a light if the light is installed above or below the horizontal plane passing through the threshold.

The correct elevation-setting angle for such a light is

$$\phi' = \tan^{-1} (h - \Delta h)/D_o \qquad \text{(III-34)}$$

where

Δh is the height of the light above the horizontal plane passing through the threshold;
D_o is the designated distance; and
ϕ' is the corrected elevation-setting angle. (See Figure III-11)

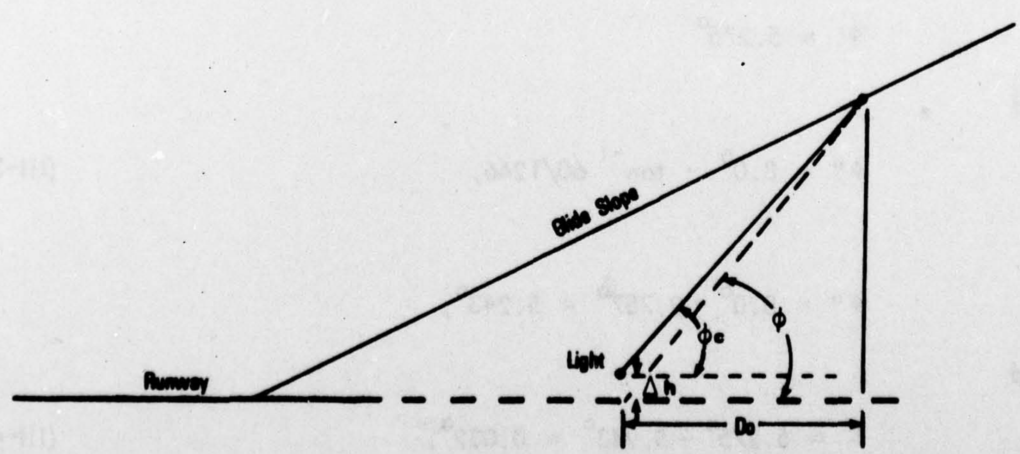

Figure III-11. Correction of Elevation-Setting Angle for Approach Lights Displaced from the Horizontal Plane Passing Through the Threshold

Also,

$$h = D_o \tan \phi$$

where ϕ is the elevation-setting angle for a light installed on the horizontal plane passing through the threshold.

Therefore,

$$\phi' = \tan^{-1} [(D_o \tan \phi - \Delta h)/D_o]. \tag{III-35}$$

A simpler approximate solution, ϕ'', is given by

$$\phi'' = \phi - \tan^{-1} (\Delta h/D_o). \tag{III-36}$$

Let ε be the difference between the two solutions. Then

$$\varepsilon = \phi' - \phi''. \tag{III-37}$$

For a light at Station 3000, the maximum value of Δh is 60 feet for a positive slope and -30 feet for a negative slope [10]. Using the distance of 60 feet for Δh,

$$\phi = \tan^{-1} [(1246 \tan 8.0^\circ - 60)/1246] \tag{III-38}$$

or

$$\phi' = 5.275^\circ$$

and

$$\phi'' = 8.0^\circ - \tan^{-1} 60/1246, \tag{III-39}$$

or

$$\phi'' = 8.0^\circ - 2.757^\circ = 5.243^\circ,$$

and

$$\varepsilon = 5.275^\circ - 5.243^\circ = 0.032^\circ. \tag{III-40}$$

This value of ϵ is the largest error. For example, for a light at Station 1000, ϕ is 6.7°, and $\Delta h = 20$ or -10. So for $\Delta h = 20$,

$$\phi' = 5.791^\circ$$

and

$$\phi'' = 5.780^\circ.$$

Therefore,

$$\epsilon = 0.011^\circ.$$

Thus, the error in the approximate solution will not be greater than 0.03°. The approximate solution will, of course, occasionally cause a difference of 0.1° in the elevation-setting angle when the angles are rounded to the nearest 0.1°, as is the case for the light at Station 3000. The effect of this is considered insignificant. For example, angles are rounded to the nearest 0.5° in tables 2-1 and 2-2 of the Aerodrome Design Manual [20].

APPENDIX IV

LIGHT INTENSITY DISTRIBUTIONS

This Appendix contains detailed intensity distributions of the lights used in approach-light systems at U.S. civil airports as follows:

Figure IV-1: 150PAR38/SP manufactured by Sylvania. The data presented are the averages obtained from three lamps measured by NAFEC for this study.

Figure IV-2: 150PAR38/SP manufactured by Westinghouse. The data presented are the averages of three lamps measured at NAFEC for this study.

Figure IV-3: 150PAR38/SP manufactured by General Electric and marked as lot 64. The data presented are the averages of three lamps measured at NAFEC for this study.

Figure IV-4: As Figure IV-3, except lot number is 88.

Figure IV-5: Q20A/PAR56 manufactured by General Electric. The data presented represent one lamp measured at NAFEC for this study.

Figure IV-6: FT34/HP - a condenser-discharge lamp manufactured by General Electric. As data from NAFEC were not available, NBS measurements were used. The data represent one lamp and were obtained from NBS Report 9350 [g].

All measurements were made using the peak of the beam as the origin to minimize the effects of random deviations of the beam axes of the lamps from their optical axes. (In service, lights are aligned using the optical axes of the lamps as a reference.)

To assist in intercomparisons of lamps, the ICAO-defined angular subtense of the lights are indicated by solid lines to the extent permitted by the angular increments of the data. In addition, since the U.S. has used $\pm 15^{o}$ as the lateral boundaries since 1948, these boundaries are indicated by broken lines.

	-15	-14	-13	-12	-11	-10	-9	-8	-7	-6	-5	-4	-3	-2	-1	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	
15																																15
14																																14
13				.8	.9	.9	1.0	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.7	1.7	1.0	1.0	1.5	1.4	1.3	1.2	1.1	1.1	1.0	.6	.7	.8				13
12				.8	.9	1.0	1.1	1.2	1.4	1.6	1.8	1.9	2.1	2.2	2.2	2.1	2.0	1.9	1.8	1.6	1.5	1.4	1.3	1.2	1.1	1.0	1.0	.9				12
11				.9	1.0	1.1	1.2	1.4	1.7	2.0	2.3	2.5	2.6	2.7	2.6	2.5	2.4	2.3	2.1	2.0	1.8	1.6	1.4	1.3	1.2	.8	1.0	.9				11
10				1.0	1.0	1.2	1.5	1.7	2.1	2.5	2.8	3.1	3.1	3.1	3.0	2.9	2.8	2.7	2.6	2.3	2.1	1.9	1.7	1.5	1.3	1.2	1.1	1.0				10
9				1.0	1.2	1.4	1.7	2.1	2.5	3.0	3.3	3.5	3.6	3.6	3.5	3.4	3.3	3.2	3.0	2.8	2.6	2.3	2.0	1.7	1.9	1.3	1.2	1.1				9
8				1.1	1.3	1.6	2.0	2.4	2.9	3.3	3.7	4.0	4.2	4.1	4.1	4.1	4.0	3.8	3.6	3.3	3.0	2.8	2.4	2.1	1.8	1.5	1.4	1.2				8
7				1.1	1.4	1.8	2.2	2.6	3.1	3.6	4.1	4.5	4.7	4.8	4.9	4.9	4.8	4.7	4.7	4.0	3.6	3.2	2.8	2.4	2.1	1.8	1.6	1.4				7
6				1.2	1.5	1.9	2.4	2.9	2.8	3.3	4.4	5.0	5.3	5.6	5.7	5.8	5.8	5.6	5.3	4.8	4.3	3.8	3.3	2.8	2.4	2.1	1.3	1.5				6
5				1.3	1.7	2.1	2.5	3.0	3.6	4.2	4.9	5.5	6.1	6.5	6.8	6.9	6.8	6.7	6.4	5.9	5.2	4.4	3.7	3.2	2.2	2.4	2.1	1.8				5
4				1.4	1.8	2.2	2.6	3.2	3.9	4.8	5.5	6.3	7.0	7.7	8.2	8.2	8.0	7.7	7.3	6.8	6.1	5.2	4.3	3.6	3.0	2.6	2.3	2.0				4
3				1.5	1.9	2.3	2.9	3.5	4.4	5.4	6.3	7.0	7.8	8.8	9.6	9.6	9.2	8.7	8.2	7.6	6.9	6.1	5.0	4.2	4.3	2.9	2.5	2.5				3
2				1.6	1.9	2.4	3.0	3.9	4.8	5.9	6.8	7.6	8.6	9.6	10.8	11.2	10.6	9.6	8.7	8.1	7.6	6.9	5.7	4.7	3.8	3.2	2.7	2.3				2
1				1.6	2.0	2.5	3.2	4.1	5.1	6.2	7.1	8.0	9.1	10.5	11.8	12.7	12.1	10.6	9.2	8.4	7.9	7.3	6.2	5.1	4.2	3.5	3.0	2.4				1
0				1.7	2.1	2.6	3.3	4.3	5.4	4.4	7.3	8.2	9.5	10.8	12.4	13.4	12.8	11.2	9.6	8.6	8.0	7.4	6.2	5.1	4.3	3.6	3.1	2.5				0
-1				1.7	2.1	2.6	3.3	4.3	5.4	6.5	7.4	8.4	9.5	10.5	11.8	12.8	12.5	11.2	9.8	8.7	8.1	7.5	6.3	5.2	4.4	3.7	3.1	2.6				-1
-2				1.7	2.1	2.6	3.3	4.2	5.3	6.4	7.5	8.5	9.2	9.8	10.7	11.5	11.5	10.7	9.6	8.8	8.1	7.4	6.3	5.2	4.3	3.6	3.0	2.5				-2
-3				1.7	2.1	2.6	3.2	4.0	5.0	6.1	7.2	8.2	8.7	9.1	9.5	10.2	10.6	10.3	9.5	8.8	8.1	7.2	6.1	5.1	4.2	3.5	2.9	2.4				-3
-4				1.6	2.0	2.5	3.1	3.8	4.6	5.7	6.8	7.6	8.1	8.5	8.9	9.4	9.9	9.8	9.2	8.5	7.7	6.7	5.7	4.8	4.0	3.4	2.8	2.4				-4
-5				1.6	2.0	2.4	2.9	3.6	4.2	5.1	6.0	6.8	7.4	7.8	8.2	8.7	9.0	9.0	8.5	7.8	7.0	6.0	5.1	4.4	3.7	3.1	2.7	2.3				-5
-6				1.5	1.9	2.3	2.8	3.3	3.8	4.4	5.2	5.7	6.4	7.0	7.4	7.7	7.9	7.8	7.4	6.9	6.1	5.3	4.6	4.0	3.5	2.9	2.5	2.1				-6
-7				1.3	1.7	2.1	2.5	3.0	3.5	4.0	4.6	5.1	5.6	6.0	6.4	6.7	6.9	6.8	6.6	6.2	5.5	4.8	4.3	3.8	3.2	2.8	2.4	2.0				-7
-8				1.2	1.5	1.8	2.2	2.6	3.0	3.5	3.9	4.4	4.8	5.2	5.5	5.7	5.9	6.1	6.1	5.8	5.3	4.7	4.1	3.6	3.1	2.6	2.1	1.7				-8
-9				1.0	1.3	1.6	1.9	2.2	2.5	2.9	3.3	3.8	4.2	4.5	4.7	4.9	5.2	5.4	5.5	5.3	4.9	4.4	3.9	3.4	2.8	2.3	1.8	1.5				-9
-10				1.0	1.1	1.3	1.6	1.8	2.1	2.4	2.7	3.0	3.4	3.8	4.0	4.3	4.5	4.7	4.7	4.6	4.4	4.0	3.5	3.0	2.4	2.0	1.5	1.3				-10
-11				.9	1.0	1.1	1.3	1.5	1.8	2.0	2.3	2.5	2.8	3.1	3.4	3.6	3.8	4.0	4.0	3.9	3.7	3.3	2.9	2.4	1.9	1.6	1.3	1.1				-11
-12				.8	.9	1.0	1.1	1.2	1.4	1.7	1.9	2.1	2.4	2.6	2.8	3.0	3.2	3.2	3.3	3.2	2.9	2.6	2.2	1.8	1.5	1.2	1.1	.9				-12
-13				.8	.9	.9	1.0	1.0	1.2	1.3	1.6	1.8	1.9	2.1	2.3	2.4	2.5	2.5	2.5	2.3	2.1	1.9	1.6	1.3	1.1	1.0	.9	.8				-13
-14				.7	.8	.8	.9	.9	1.0	1.1	1.2	1.4	1.5	1.7	1.8	1.8	1.9	1.8	1.8	1.7	1.5	1.3	1.2	1.0	.9	.9	.8	.8				-14
-15				.7	.7	.8	.8	.9	.9	.9	1.0	1.1	1.2	1.2	1.3	1.4	1.4	1.3	1.3	1.2	1.1	1.0	1.0	.9	.8	.8	.7	.7				-15
	-15	-14	-13	-12	-11	-10	-9	-8	-7	-6	-5	-4	-3	-2	-1	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	

Notes: —— ICAU boundaries

– – – U.S. lateral boundaries

Representative intensity: 5.6 kilocandelas

Figure IV-1: Intensity distribution data in kilocandelas of Sylvania type 150PAR38/SP lamps; average of three lamps

	-15	-14	-13	-12	-11	-10	-9	-8	-7	-6	-5	-4	-3	-2	-1	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	
15	.7	.7	.8	.8	.8	.9	.9	.9	1.0	1.0	1.0	1.1	1.1	1.1	1.2	1.2	1.2	1.2	1.1	1.1	1.0	1.0	1.0	.9	.9	.8	.8	.7	.7	.7	.6	15
14	.8	.8	.8	.9	.9	.9	1.0	1.0	1.1	1.1	1.2	1.2	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.2	1.2	1.1	1.1	1.0	1.0	.9	.9	.8	.8	.7	.7	14
13	.8	.8	.9	.9	1.0	1.0	1.1	1.2	1.2	1.3	1.4	1.4	1.5	1.5	1.6	1.6	1.6	1.5	1.5	1.4	1.4	1.3	1.2	1.2	1.1	1.0	1.0	.9	.8	.8	.7	13
12	.8	.9	1.0	1.0	1.1	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.8	1.8	1.9	1.8	1.2	1.8	1.7	1.6	1.5	1.4	1.3	1.2	1.2	1.1	1.0	.9	.9	.8	12
11	.9	1.0	1.0	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.9	2.0	2.1	2.2	2.2	2.2	2.2	2.2	2.1	2.0	1.9	1.8	1.7	1.5	1.4	1.3	1.2	1.1	1.0	1.0	.9	11
10	1.0	1.0	1.1	1.2	1.3	1.4	1.6	1.7	1.9	2.0	2.2	2.4	2.5	2.6	2.6	2.6	2.6	2.6	2.5	2.4	2.2	2.1	1.9	1.8	1.6	1.5	1.4	1.3	1.2	1.1	1.0	10
9	1.0	1.1	1.2	1.3	1.4	1.6	1.8	2.0	2.2	2.4	2.6	2.8	3.0	3.1	3.1	3.2	3.1	3.1	3.0	2.8	2.6	2.5	2.3	2.1	1.9	1.7	1.6	1.4	1.3	1.2	1.1	9
8	1.1	1.2	1.3	1.4	1.6	1.8	2.0	2.2	2.5	2.8	3.1	3.3	3.5	3.6	3.7	3.7	3.1	3.6	3.5	3.3	3.1	2.9	2.6	2.4	2.2	2.0	1.8	1.6	1.4	1.3	1.2	8
7	1.1	1.2	1.4	1.5	1.7	2.0	2.2	2.6	2.9	3.3	3.6	3.9	4.2	4.3	4.4	4.4	4.4	4.3	4.1	3.9	3.7	3.4	3.1	2.8	2.5	2.3	2.0	1.8	1.6	1.4	1.3	7
6	1.2	1.3	1.5	1.6	1.9	2.2	2.5	2.9	3.3	3.8	4.2	4.6	4.8	5.0	5.2	5.2	5.2	5.0	4.8	4.9	4.3	3.9	3.6	3.2	2.8	2.5	2.3	2.0	1.8	1.6	1.4	6
5	1.2	1.4	1.5	1.7	2.0	2.4	2.7	3.2	3.7	4.3	4.8	5.2	5.6	5.8	6.0	6.0	6.0	5.8	5.5	5.2	4.9	4.5	4.0	3.7	3.2	2.8	2.5	2.2	1.9	1.7	1.5	5
4	1.3	1.4	1.6	1.8	2.1	2.5	3.0	3.5	4.1	4.7	5.3	5.3	6.3	6.6	6.8	6.8	6.7	6.5	6.3	5.9	5.4	5.0	4.5	4.0	3.6	3.1	2.7	2.4	2.1	1.8	1.6	4
3	1.3	1.4	1.7	1.9	2.2	2.6	3.2	3.8	4.4	5.2	5.8	6.4	7.0	7.3	7.5	7.6	7.5	7.3	6.9	6.5	6.0	5.5	4.9	4.4	3.9	3.4	2.9	2.5	2.2	1.9	1.6	3
2	1.3	1.5	1.7	1.9	2.3	2.7	3.3	4.0	4.7	5.4	6.2	6.9	7.4	7.9	8.1	8.2	8.1	7.8	7.4	7.0	6.4	5.9	5.3	4.7	4.1	3.6	3.1	2.6	2.3	1.9	1.7	2
1	1.3	1.5	1.7	1.9	2.3	2.8	3.4	4.1	4.3	5.6	6.5	7.1	7.7	8.2	8.5	8.6	8.5	8.2	7.8	7.3	6.7	6.2	5.5	4.9	4.3	3.7	3.2	2.7	2.3	2.0	1.7	1
0	1.3	1.4	1.7	1.9	2.3	2.7	3.3	4.1	4.8	5.7	6.4	7.3	7.8	8.3	8.6	8.7	8.7	8.4	8.0	7.5	6.0	6.3	5.6	5.0	4.4	3.8	3.2	2.8	2.3	2.0	1.7	0
-1	1.3	1.4	1.6	1.9	2.2	2.7	3.3	3.9	4.7	5.5	6.4	7.1	7.7	8.1	8.4	8.6	8.5	8.3	7.9	7.4	6.8	6.2	5.6	5.0	4.3	3.8	3.2	2.7	2.3	2.0	1.7	-1
-2	1.2	1.4	1.6	1.9	2.2	2.6	3.1	3.8	4.5	5.3	6.0	6.7	7.3	7.7	8.0	8.2	8.1	7.9	7.6	7.1	6.5	5.9	5.4	4.8	4.2	3.6	3.1	2.7	2.2	1.9	1.7	-2
-3	1.2	1.4	1.5	1.8	2.1	2.5	3.0	3.5	4.2	4.8	5.6	6.1	6.7	7.1	7.4	7.6	7.5	7.3	7.0	6.6	6.1	5.6	5.0	4.5	3.9	3.4	3.0	2.5	2.2	1.8	1.6	-3
-4	1.2	1.3	1.5	1.7	2.0	2.3	2.8	3.2	3.8	4.4	5.0	5.6	6.1	6.5	6.8	6.9	6.9	6.7	6.5	6.0	5.6	5.1	4.7	4.2	3.7	3.2	2.8	2.4	2.1	1.8	1.5	-4
-5	1.2	1.3	1.4	1.6	1.9	2.2	2.5	3.0	3.4	3.9	4.4	4.9	5.4	5.7	6.0	6.1	6.1	6.0	5.7	5.4	5.0	4.6	4.2	3.8	3.3	2.9	2.5	2.2	1.9	1.7	1.4	-5
-6	1.1	1.2	1.4	1.5	1.7	2.0	2.3	2.7	3.0	3.5	3.9	4.3	4.7	5.0	5.2	5.3	5.3	5.2	5.0	4.8	4.4	4.1	3.7	3.4	3.0	2.6	2.3	2.0	1.8	1.5	1.4	-6
-7	1.1	1.2	1.3	1.4	1.6	1.8	2.1	2.4	2.7	3.1	3.4	3.7	4.0	4.3	4.4	4.5	4.5	4.5	4.3	4.1	3.8	3.5	3.2	2.9	2.6	2.3	2.1	1.8	1.6	1.4	1.3	-7
-8	1.0	1.1	1.2	1.3	1.5	1.7	1.9	2.1	2.4	2.7	3.0	3.2	3.4	3.6	3.7	3.8	3.8	3.8	3.7	3.5	3.3	3.0	2.8	2.5	2.3	2.1	1.8	1.6	1.5	1.3	1.2	-8
-9	.9	1.0	1.1	1.2	1.3	1.5	1.7	1.9	2.1	2.3	2.5	2.7	2.9	3.0	3.1	3.2	3.2	3.2	3.1	2.9	2.8	2.6	2.4	2.2	2.0	1.8	1.6	1.5	1.3	1.2	1.1	-9
-10	.9	1.0	1.0	1.1	1.2	1.3	1.5	1.6	1.8	2.0	2.2	2.3	2.4	2.6	2.6	2.7	2.7	2.6	2.6	2.4	2.3	2.2	2.0	1.8	1.7	1.6	1.4	1.3	1.2	1.1	1.0	-10
-11	.8	.9	.9	1.0	1.1	1.2	1.3	1.4	1.6	1.7	1.8	2.0	2.0	2.1	2.2	2.2	2.2	2.2	2.1	2.0	1.9	1.8	1.7	1.6	1.5	1.4	1.2	1.1	1.1	1.0	.9	-11
-12	.8	.8	.9	.9	1.0	1.1	1.2	1.2	1.4	1.4	1.5	1.6	1.7	1.8	1.8	1.8	1.8	1.8	1.8	1.7	1.6	1.5	1.4	1.4	1.3	1.2	1.1	1.0	.9	.9	.8	-12
-13	.7	.7	.8	.8	.9	.9	1.0	1.1	1.2	1.2	1.3	1.4	1.4	1.5	1.5	1.6	1.6	1.5	1.5	1.4	1.4	1.3	1.2	1.2	1.1	1.0	1.0	.9	.8	.8	.7	-13
-14	.6	.7	.7	.8	.8	.8	.9	1.0	1.0	1.1	1.1	1.2	1.2	1.3	1.3	1.3	1.3	1.3	1.3	1.2	1.2	1.1	1.1	1.0	1.0	.9	.9	.8	.8	.7	.7	-14
-15	.6	.6	.7	.7	.7	.8	.8	.8	.9	.9	1.0	1.0	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.0	1.0	.9	.9	.9	.8	.8	.7	.7	.7	.6	-15
	-15	-14	-13	-12	-11	-10	-9	-8	-7	-6	-5	-4	-3	-2	-1	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	

Notes: ——— ICAO boundaries

– – – U.S. lateral boundaries

Representative intensity 5.7 kilocandelas

Figure IV-2: Intensity distribution data in kilocandelas of Westinghouse type 150PAR38/SP lamps; average of three lamps

	-15	-14	-13	-12	-11	-10	-9	-8	-7	-6	-5	-4	-3	-2	-1	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
15	.7	.8	.8	.8	.9	.9	.9	.9	1.0	1.0	1.1	1.2	1.2	1.3	1.4	1.5	1.5	1.5	1.5	1.4	1.4	1.3	1.3	1.2	1.1	1.1	1.1	1.0	.9	.8	.8
14	.8	.8	.8	.9	.9	1.0	1.0	1.0	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.8	1.9	1.8	1.7	1.6	1.5	1.4	1.3	1.3	1.2	1.1	1.1	1.0	.9	.8
13	.8	.8	.9	.9	1.0	1.0	1.0	1.1	1.2	1.3	1.4	1.6	1.7	1.8	2.0	2.1	2.2	2.2	2.1	2.0	1.9	1.8	1.6	1.5	1.4	1.3	1.2	1.1	1.1	1.0	.9
12	.8	.8	.9	1.0	1.0	1.1	1.1	1.2	1.3	1.4	1.6	1.8	2.0	2.1	2.3	2.4	2.5	2.5	2.4	2.3	2.1	2.0	1.8	1.6	1.5	1.4	1.3	1.2	1.1	1.0	.9
11	.8	.8	.9	1.0	1.0	1.1	1.2	1.3	1.4	1.6	1.8	2.1	2.3	2.5	2.7	2.8	2.9	2.9	2.8	2.7	2.5	2.2	2.0	1.8	1.6	1.5	1.4	1.3	1.1	1.0	.9
10	.8	.9	.9	1.0	1.1	1.2	1.3	1.4	1.6	1.8	2.1	2.4	2.7	2.9	3.1	3.3	3.3	3.3	3.2	3.0	2.8	2.5	2.3	2.0	1.8	1.6	1.5	1.3	1.2	1.0	.9
9	.8	.9	.9	1.0	1.1	1.2	1.4	1.5	1.8	2.1	2.4	2.8	3.1	3.4	3.6	3.8	3.9	3.8	3.7	3.5	3.2	2.9	2.6	2.2	2.0	1.8	1.6	1.4	1.2	1.0	.9
8	.8	.9	1.0	1.1	1.2	1.3	1.5	1.8	2.0	2.4	2.8	3.3	3.7	4.0	4.3	4.5	4.5	4.4	4.2	4.0	3.7	3.4	3.0	2.6	2.3	2.0	1.7	1.5	1.3	1.1	1.0
7	.8	.9	1.0	1.2	1.3	1.5	1.7	2.0	2.4	2.8	3.3	3.8	4.3	4.7	5.0	5.2	5.3	5.1	4.8	4.5	4.2	3.9	3.5	3.0	2.6	2.2	1.9	1.6	1.4	1.2	1.0
6	.8	.9	1.1	1.3	1.5	1.7	2.0	2.4	2.8	3.2	3.8	4.4	5.0	5.4	5.7	6.0	6.1	5.8	5.5	5.1	4.7	4.3	3.9	3.4	3.0	2.5	2.1	1.8	1.5	1.2	1.0
5	.9	1.0	1.2	1.4	1.7	2.0	2.4	2.8	3.2	3.8	4.4	5.0	5.7	6.1	6.5	6.7	6.8	6.6	6.2	5.8	5.3	4.9	4.4	3.9	3.3	2.9	2.4	2.0	1.6	1.3	1.1
4	.9	1.1	1.3	1.6	1.9	2.3	2.8	3.3	3.8	4.4	5.0	5.7	6.4	6.9	7.2	7.4	7.5	7.3	7.0	6.5	5.9	5.4	4.9	4.3	3.6	3.1	2.6	2.1	1.7	1.4	1.2
3	1.0	1.2	1.4	1.8	2.2	2.8	3.1	3.7	4.3	4.9	5.6	6.3	7.0	7.6	8.0	8.2	8.3	8.1	7.6	7.1	6.5	6.0	5.3	4.7	4.0	3.4	2.8	2.2	1.8	1.5	1.2
2	1.0	1.3	1.6	2.0	2.5	2.9	3.5	4.1	4.7	5.4	6.1	6.9	7.6	8.2	8.7	8.9	8.9	8.7	8.2	7.7	7.1	6.4	5.7	5.0	4.2	3.6	2.9	2.4	1.9	1.5	1.3
1	1.1	1.4	1.7	2.1	2.6	3.2	3.8	4.4	5.1	5.7	6.5	7.2	8.0	8.6	9.1	9.4	9.4	9.2	8.6	8.0	7.5	6.7	6.0	5.2	4.4	3.7	3.1	2.5	2.0	1.6	1.3
0	1.2	1.4	1.8	2.2	2.8	3.4	3.9	4.6	5.2	5.8	6.5	7.2	7.9	8.6	9.1	9.4	9.5	9.2	8.6	8.1	7.5	6.8	6.0	5.3	4.4	3.8	3.1	2.5	2.1	1.6	1.3
-1	1.2	1.5	1.8	2.3	2.9	3.4	4.0	4.6	5.0	5.6	6.2	6.8	7.5	8.2	8.7	9.1	9.2	8.9	8.4	7.9	7.4	6.7	5.9	5.2	4.5	3.7	3.1	2.5	2.1	1.7	1.3
-2	1.2	1.5	1.9	2.3	2.9	3.5	4.1	4.5	4.9	5.3	5.8	6.3	6.9	7.5	8.1	8.5	8.6	8.4	8.1	7.6	7.1	6.5	5.8	5.1	4.4	3.6	3.1	2.5	2.0	1.6	1.3
-3	1.2	1.5	1.9	2.4	2.8	3.4	3.9	4.3	4.6	4.9	5.3	5.8	6.3	6.8	7.3	7.7	7.8	7.7	7.5	7.2	6.8	6.2	5.5	4.8	4.1	3.5	2.9	2.3	1.9	1.6	1.3
-4	1.2	1.5	1.8	2.3	2.7	3.3	3.7	4.0	4.3	4.6	4.9	5.3	5.7	6.2	6.6	7.0	7.1	7.2	7.0	6.8	6.4	5.9	5.2	4.5	3.9	3.2	2.7	2.2	1.8	1.5	1.3
-5	1.2	1.4	1.8	2.2	2.7	3.1	3.5	3.8	4.0	4.2	4.5	4.8	5.2	5.6	6.0	6.4	6.5	6.6	6.5	6.3	5.9	5.4	4.8	4.1	3.5	3.0	2.5	2.1	1.7	1.4	1.2
-6	1.1	1.4	1.7	2.1	2.5	2.9	3.3	3.6	3.8	3.9	4.1	4.4	4.7	5.1	5.4	5.7	6.0	6.0	5.9	5.7	5.4	4.9	4.3	3.7	3.1	2.7	2.3	1.9	1.6	1.3	1.2
-7	1.1	1.3	1.6	2.0	2.4	2.7	3.1	3.4	3.5	3.7	3.8	4.0	4.3	4.5	4.8	5.1	5.3	5.3	5.2	5.0	4.7	4.2	3.7	3.2	2.8	2.4	2.0	1.7	1.5	1.3	1.1
-8	1.0	1.2	1.5	1.8	2.2	2.6	2.9	3.1	3.3	3.5	3.6	3.7	3.9	4.1	4.3	4.5	4.6	4.6	4.5	4.4	4.0	3.6	3.2	2.8	2.4	2.0	1.8	1.5	1.3	1.2	1.1
-9	.9	1.1	1.4	1.7	2.0	2.3	2.6	2.8	3.0	3.1	3.2	3.4	3.5	3.7	3.8	4.0	4.0	4.0	3.9	3.7	3.4	3.0	2.7	2.3	2.0	1.7	1.5	1.4	1.2	1.1	1.0
-10	.9		1.2	1.5	1.8	2.0	2.2	2.4	2.6	2.7	2.8	2.9	3.1	3.2	3.3	3.4	3.4	3.3	3.2	3.0	2.8	2.6	2.2	2.0	1.7	1.5	1.4	1.3	1.2	1.1	1.0
-11	.8	.9	1.1	1.3	1.5	1.7	1.9	2.0	2.1	2.2	2.3	2.4	2.6	2.6	2.7	2.8	2.8	2.7	2.6	2.5	2.3	2.1	1.9	1.7	1.5	1.3	1.2	1.2	1.1	1.0	.9
-12	.7	.8	1.0	1.1	1.2	1.4	1.5	1.6	1.7	1.8	1.9	2.0	2.1	2.2	2.2	2.2	2.3	2.2	2.1	2.0	1.9	1.7	1.6	1.4	1.3	1.2	1.1	1.0	1.0	.9	.8
-13	.7	.7	.8	.9	1.0	1.2	1.2	1.3	1.4	1.4	1.5	1.6	1.6	1.7	1.8	1.8	1.8	1.7	1.7	1.6	1.5	1.4	1.3	1.2	1.1	1.0	1.0	1.0	.9	.8	.8
-14	.6	.7	.7	.8	.9	1.0	1.0	1.1	1.1	1.1	1.2	1.2	1.3	1.3	1.4	1.4	1.4	1.4	1.3	1.3	1.2	1.1	1.1	1.0	1.0	.9	.9	.9	.8	.8	.7
-15	.6	.6	.7	.7	.8	.9	.9	.9	.9	.9	1.0	1.0	1.0	1.1	1.1	1.1	1.1	1.1	1.1	1.0	1.0	.9	.9	.9	.8	.8	.8	.8	.7	.7	.6

Notes: —— ICAO boundaries

– – U.S. lateral boundaries

Representative intensity 5.6 kilocandelas

Figure IV-3: Intensity distribution data in kilocandelas of General Electric type 150PAR38/SP lamps, lot 64; average of three lamps

	-15	-14	-13	-12	-11	-10	-9	-8	-7	-6	-5	-4	-3	-2	-1	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
15																															
14	.7	.7	.8	.8	.8	.8	.9	.9	.9	.9	.9	.9	1.0	1.0	1.0	1.0	1.0	1.0	1.1	1.1	1.1	1.0	1.0	1.0	.9	.8	.8	.7	.6	.6	.6
13	.7	.8	.8	.9	.9	.9	.9	.9	.9	1.0	1.0	1.0	1.0	1.0	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.0	1.0	.9	.8	.7	.7	.6	.6
12	.8	.9	.9	.9	1.0	1.0	1.0	1.0	1.0	1.0	1.1	1.1	1.1	1.1	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.1	1.1	1.1	1.0	.9	.9	.8	.7	.6	.6
11	.8	.9	1.0	1.0	1.0	1.1	1.1	1.1	1.1	1.1	1.2	1.2	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.2	1.2	1.2	1.1	1.0	.9	.8	.8	.7	.6
10	.9	1.0	1.0	1.0	1.1	1.1	1.1	1.2	1.2	1.3	1.3	1.4	1.4	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.4	1.3	1.3	1.2	1.1	1.0	.9	.8	.7	.7
9	1.0	1.0	1.1	1.1	1.1	1.2	1.2	1.3	1.4	1.5	1.6	1.6	1.7	1.8	1.8	1.9	1.9	1.8	1.8	1.7	1.7	1.6	1.5	1.4	1.3	1.2	1.1	1.0	.9	.8	.7
8	1.0	1.0	1.1	1.1	1.2	1.2	1.3	1.4	1.6	1.7	1.8	2.0	2.1	2.2	2.2	2.3	2.3	2.3	2.2	2.1	2.0	1.9	1.8	1.7	1.5	1.4	1.2	1.1	.9	.9	.8
7	1.0	1.0	1.1	1.2	1.2	1.3	1.4	1.6	1.8	2.0	2.2	2.4	2.6	2.7	2.9	3.0	3.0	2.9	2.7	2.6	2.5	2.3	2.2	2.0	1.8	1.6	1.4	1.2	1.1	1.0	.9
6	1.0	1.1	1.1	1.2	1.3	1.4	1.6	1.8	2.0	2.3	2.6	2.9	3.2	3.4	3.6	3.7	3.7	3.6	3.4	3.2	3.0	2.8	2.6	2.4	2.1	1.8	1.6	1.4	1.2	1.0	.9
5	1.0	1.1	1.2	1.3	1.4	1.6	1.8	2.0	2.4	2.8	3.2	3.6	3.9	4.2	4.4	4.6	4.6	4.4	4.2	3.9	3.7	3.4	3.1	2.8	2.5	2.2	1.9	1.5	1.3	1.1	1.0
4	1.1	1.1	1.2	1.3	1.5	1.7	2.0	2.3	2.8	3.3	3.7	4.2	4.7	5.0	5.3	5.5	5.5	5.3	5.1	4.7	4.3	4.0	3.6	3.3	2.9	2.5	2.1	1.8	1.4	1.2	1.1
3	1.1	1.2	1.3	1.4	1.6	1.9	2.2	2.7	3.2	3.8	4.3	4.9	5.5	6.0	4.0	6.6	6.6	6.3	6.0	5.6	5.1	4.6	4.2	3.7	3.3	2.8	2.4	1.9	1.6	1.3	1.2
2	1.1	1.2	1.3	1.5	1.8	2.1	2.5	3.1	3.6	4.2	4.9	5.6	6.3	6.9	7.5	7.8	7.7	7.4	6.9	6.4	5.8	5.3	4.7	4.2	3.6	3.1	2.6	2.1	1.7	1.4	1.2
1	1.1	1.2	1.4	1.6	1.9	2.3	2.8	3.4	4.1	4.8	5.6	6.3	7.0	7.8	8.5	8.8	8.6	8.2	7.6	7.1	6.5	5.9	5.2	4.6	3.9	3.4	2.8	2.3	1.8	1.5	1.3
0	1.1	1.2	1.5	1.7	2.1	2.6	3.1	3.8	4.5	5.4	6.2	7.0	7.7	8.3	8.8	9.0	9.0	8.5	8.0	7.5	6.9	6.4	5.7	4.9	4.3	3.6	2.9	2.4	2.0	1.6	1.4
-1	1.1	1.3	1.5	1.8	2.2	2.8	3.4	4.1	4.9	5.9	6.8	7.6	8.0	8.2	8.3	8.5	8.6	8.3	7.8	7.4	7.1	6.6	5.9	5.2	4.5	3.5	3.1	2.5	2.0	1.6	1.4
-2	1.1	1.3	1.6	2.0	2.4	3.0	3.6	4.4	5.2	6.2	7.2	7.8	7.9	7.8	7.7	7.8	7.9	7.9	7.6	7.3	7.0	6.6	6.1	5.4	4.6	3.9	3.2	2.6	2.0	1.6	1.4
-3	1.2	1.4	1.7	2.1	2.6	3.2	3.9	4.6	5.5	6.3	7.1	7.5	7.6	7.4	7.3	7.2	7.4	7.6	7.4	7.2	6.9	6.6	6.0	5.4	4.7	3.9	3.1	2.5	2.0	1.6	1.3
-4	1.2	1.4	1.7	2.2	2.7	3.3	4.0	4.8	5.6	6.3	6.9	7.2	7.2	7.1	7.0	7.1	7.2	7.4	7.4	7.2	6.8	6.5	6.0	5.4	4.7	3.8	3.1	2.5	2.0	1.6	1.3
-5	1.2	1.5	1.8	2.2	2.7	3.3	4.0	4.8	5.6	6.2	6.7	6.9	7.0	6.9	6.9	6.9	7.1	7.3	7.3	7.1	6.8	6.3	5.8	5.3	4.5	3.8	3.0	2.4	1.9	1.5	1.2
-6	1.3	1.5	1.8	2.2	2.7	3.3	4.0	4.8	5.1	6.1	6.5	6.7	6.8	6.9	6.8	6.8	6.9	7.1	7.1	6.9	6.6	6.2	5.7	5.0	4.3	3.5	2.9	2.3	1.9	1.5	1.2
-7	1.2	1.5	1.8	2.2	2.6	3.1	3.8	4.5	5.3	5.8	6.3	6.5	6.6	6.7	6.7	6.7	6.8	6.8	6.8	6.6	6.3	5.9	5.3	4.7	4.0	3.3	2.8	2.2	1.7	1.4	1.1
-8	1.2	1.4	1.7	2.0	2.5	3.0	3.6	4.2	4.9	5.5	5.9	6.2	6.4	6.5	6.5	6.6	6.6	6.5	6.4	6.2	5.8	5.4	4.8	4.2	3.5	3.0	2.4	2.0	1.6	1.3	1.1
-9	1.2	1.4	1.6	1.9	2.3	2.8	3.3	3.8	4.5	5.0	5.5	5.8	6.1	6.2	6.3	6.3	6.3	6.2	5.9	5.6	5.2	4.6	4.1	3.6	3.1	2.6	2.2	1.8	1.5	1.2	
-10	1.1	1.3	1.5	1.8	2.1	2.5	3.0	3.5	3.9	4.4	4.9	5.3	5.6	5.8	5.8	5.8	5.8	5.6	5.3	4.9	4.4	3.9	3.5	3.0	2.6	2.2	1.9	1.6	1.3	1.1	
-11	1.1	1.3	1.4	1.6	1.9	2.2	2.6	3.0	3.4	3.8	4.3	4.6	4.9	5.1	5.2	5.1	5.0	4.8	4.5	4.1	3.7	3.3	2.9	2.5	2.2	1.9	1.6	1.4	1.2	1.0	.9
-12	1.1	1.2	1.3	1.4	1.6	1.9	2.2	2.5	2.9	3.3	3.6	3.9	4.1	4.2	4.3	4.2	3.0	3.9	3.7	3.4	3.0	2.7	2.4	2.1	1.8	1.5	1.3	1.2	1.0	.9	.9
-13	1.1	1.1	1.2	1.3	1.4	1.6	1.8	2.1	2.4	2.7	3.0	3.2	3.3	3.4	3.4	3.4	3.3	3.1	2.9	2.7	2.5	2.2	1.9	1.7	1.4	1.3	1.1	1.0	.9	.8	.8
-14	1.0	1.1	1.1	1.2	1.2	1.4	1.5	1.8	2.0	2.2	2.4	2.5	2.6	2.7	2.7	2.7	2.6	2.5	2.4	2.2	2.0	1.7	1.5	1.3	1.2	1.1	1.0	.9	.8	.8	.8
-15	1.0	1.0	1.0	1.1	1.1	1.2	1.3	1.4	1.6	1.7	1.9	2.0	2.1	2.1	2.1	2.1	2.1	2.0	1.8	1.7	1.6	1.4	1.2	1.1	1.0	.9	.8	[illegible]	[illegible]	.7	.7

Notes: ——— ICAO boundaries

– – – U S lateral boundaries

Representative intensity 6.0 kilocandelas

Figure IV-4: Intensity distribution data in kilocandelas of General Electric type 150PAR38/SP lamps, lot 88; average of three lamps

	-30	-28	-26	-24	-22	-20	-18	-16	-14	-12	-10	-8	-6	-4	-2	0	2	4	6	8	10	12	14	16	18	20	22	24	26	28	30
15																															
14																															
13																															
12																															
11			1.0	1.2	1.4	1.6	1.9	2.3	2.7	2.5	2.9	3.0	3.2	3.3	3.2	3.2	3.2	3.0	2.8	2.6	2.4		2.0	1.8	1.6	1.3	1.2	1.1	1.0		
10			1.0	1.2	1.6	2.0	2.8	3.2	3.6	3.8	4.2	4.5	4.7	4.8	4.7	4.7	4.6	4.4	4.1	3.7	3.3	2.9	2.5	2.2	1.7	1.4	1.2	1.1	1.0		
9			1.1	1.4	2.0	2.9	4.0	4.8	5.2	5.7	6.5	6.9	7.2	7.4	7.4	7.4	7.2	6.8	6.3	5.7	5.0	4.2	3.5	2.9	2.3	1.6	1.3	1.1	1.0		
8			1.2	1.6	2.6	4.1	5.8	7.2	7.9	8.7	9.8	10.6	11.0	11.4	11.4	11.4	11.1	10.5	9.8	8.8	8.0	6.8	5.8	4.7	3.4	2.3	1.4	1.1	1.0		
7			1.3	1.9	3.5	5.7	8.3	10.6	11.9	13.5	14.3	15.1	15.6	16.1	16.1	16.0	15.8	15.0	14.0	13.0	12.0	11.1	9.5	7.5	5.3	3.2	1.9	1.2	1.1		
6			1.5	2.4	4.3	7.3	11.4	14.4	17.2	18.7	19.2	20.0	20.4	20.8	20.8	20.6	20.5	19.5	18.7	17.8	16.9	15.9	13.9	11.4	8.0	4.7	2.6	1.4	1.2		
5			1.8	2.7	5.1	9.5	14.0	17.8	22.3	23.4	23.4	23.4	24.0	24.5	24.8	24.7	24.5	23.6	22.9	21.9	21.2	20.6	17.8	14.6	10.8	6.6	3.7	1.9	1.4		
4			1.9	2.9	6.0	11.2	16.1	20.6	25.2	26.0	25.6	26.0	26.6	27.2	27.5	27.6	27.4	26.6	26.1	25.1	24.4	23.9	21.3	17.2	12.3	8.2	4.4	2.3	1.6		
3			2.0	3.0	6.7	11.9	17.3	23.2	27.0	27.2	27.2	27.8	28.7	29.1	29.3	29.4	29.3	28.9	28.4	27.6	26.6	25.7	23.0	19.5	14.2	9.4	5.1	2.9	1.9		
2			2.0	3.2	7.3	12.7	18.7	25.0	28.8	28.5	28.8	29.5	30.5	30.9	31.0	31.1	30.9	30.5	30.0	29.0	28.0	27.2	24.5	20.6	15.8	10.0	5.8	[illegible]	1.9		
1			2.1	3.3	7.3	13.1	20.4	25.8	30.0	29.9	30.3	31.2	31.8	32.2	32.2	32.6	32.3	31.8	31.1	30.2	29.2	28.8	26.2	21.6	16.4	10.2	5.9	2.9	1.8		
0			2.1	3.6	7.2	12.7	20.6	26.5	30.5	30.5	31.0	31.0	32.4	32.7	33.0	33.1	32.8	32.2	31.6	30.6	29.7	29.4	27.0	22.6	16.7	10.9	5.7	2.9	1.8		
-1			2.0	3.4	6.7	12.7	19.7	25.5	30.2	30.2	30.7	31.4	31.9	32.3	32.5	32.5	32.3	31.8	31.2	30.3	29.6	29.2	26.9	22.6	16.5	10.1	5.7	2.6	[illegible]		
-2			1.9	3.2	6.2	11.5	17.9	23.4	28.3	29.0	29.3	30.0	30.6	30.8	31.0	31.1	31.1	30.6	30.1	29.3	28.8	28.4	26.2	21.3	15.4	9.5	5.6	[illegible]	[illegible]		
-3			1.8	2.9	5.8	9.8	15.8	20.5	25.0	26.0	26.5	27.2	28.1	28.4	28.6	28.7	28.9	28.6	28.2	27.6	27.0	26.6	23.5	19.0	13.9	8.6	5.0	2.5	1.7		
-4			1.7	2.7	4.8	8.4	12.5	16.5	20.4	21.7	22.7	23.5	24.4	25.0	25.4	25.4	25.6	25.4	25.2	24.6	24.3	23.9	20.7	16.6	11.5	7.8	4.3	2.3	[illegible]		
-5			1.6	2.2	4.0	6.6	9.5	12.5	15.1	16.2	17.6	18.6	19.7	20.5	20.9	21.1	21.2	21.1	20.8	20.3	20.1	19.5	16.6	13.4	9.4	6.1	3.7	[illegible]	1.7		
-6			1.4	1.8	2.9	4.2	6.4	8.7	10.2	11.1	12.5	13.5	14.6	15.5	15.8	15.9	16.0	15.9	15.6	14.9	14.4	13.6	12.1	9.5	6.9	4.8	2.8	1.8	1.4		
-7			1.1	1.4	1.8	2.8	3.9	5.3	6.4	7.3	8.2	9.2	10.0	10.7	11.0	11.2	11.1	11.3	10.9	10.3	9.6	9.0	7.9	6.2	4.6	3.1	2.0	[illegible]	[illegible]		
-8			1.0	1.1	1.4	1.9	2.5	3.5	4.0	4.6	5.2	5.9	6.6	7.0	7.4	7.6	7.7	7.7	7.4	7.0	6.3	5.8	5.1	4.0	2.8	2.0	1.4	1.0	[illegible]		
-9			.9	.9	1.1	1.4	1.8	2.4	2.7	3.0	3.5	3.9	4.2	4.6	4.8	4.9	5.0	5.0	4.9	4.5	4.0	3.6	3.2	2.4	1.8	1.4	[illegible]	[illegible]	.9		
-10			.8	.9	1.0	1.2	1.4	1.7	1.9	2.1	2.5	2.7	2.8	3.0	3.1	3.2	3.3	3.3	3.2	2.9	2.6	2.4	2.2	1.7	1.4	1.2	1.0	[illegible]	[illegible]		
-11			.8	.8	.9	1.1	1.2	1.4	1.5	1.7	1.8	2.0	2.1	2.2	2.2	2.3	2.4	2.4	2.3	2.2	2.0	1.8	1.7	1.3	1.1	1.0	.9	[illegible]	[illegible]		
-12																															
-13																															
-14																															
-15																															

Notes: —— ICAO boundaries
– – U.S. lateral boundaries
Representative intensity: 28 kilocandelas

Figure IV-5: Intensity distribution data in kilocandelas of a General Electric type Q20A/PAR56 lamp

	-24	-22	-20	-18	-16	-14	-12	-10	-8	-6	-4	-2	0	2	4	6	8	10	12	14	16	18	20	22	24	
25	.8	.9	1.1	1.2	1.3	1.4	1.5	1.6	1.8	1.9	2.0	2.1	2.0	2.1	1.8	2.1	2.0	1.6	1.4	1.3	1.2	1.1	1.1	1.0	1.0	25
20	1.1	1.2	1.4	1.6	2.0	2.4	2.7	3.0	3.5	3.8	4.1	4.3	4.6	4.9	4.1	4.9	4.7	3.6	3.2	2.6	2.0	1.6	1.4	1.2	1.0	20
15	1.6	1.8	2.2	2.5	2.8	3.4	3.9	4.8	5.6	6.8	7.8	8.5	9.1	9.3	8.2	9.3	8.9	7.0	6.1	5.1	4.0	3.1	2.3	1.8	1.6	15
10	2.1	2.4	3.0	3.4	4.4	5.8	7.9	10.2	13.1	15.4	16.2	16.4	16.2	16.2	14.3	16.1	15.8	12.3	10.7	8.6	6.7	5.0	3.8	2.7	2.0	10
5	2.1	2.3	3.1	4.6	6.5	9.0	12.5	15.4	17.4	18.3	19.3	18.4	16.7	17.8	20.0	19.2	20.6	17.6	14.5	11.8	9.5	7.0	5.2	3.5	2.4	5
0	2.6	3.0	3.5	6.5	9.1	11.9	12.2	16.1	17.5	19.1	19.5	18.4	16.6	15.4	21.2	17.1	19.2	19.0	15.3	14.2	10.6	7.4	5.2	3.5	2.2	0
-5	2.0	2.4	3.0	4.1	6.0	8.6	11.1	14.0	16.2	18.2	21.8	20.4	18.0	18.1	19.0	19.9	20.0	15.7	13.4	11.9	9.4	6.8	4.6	3.2	2.2	-5
-10	1.9	2.0	2.3	2.9	3.9	5.1	7.1	9.3	11.3	13.1	14.2	15.0	15.0	15.2	12.3	15.2	14.6	11.8	10.0	8.2	5.8	3.8	2.8	2.0	1.7	-10
-15	1.4	1.6	1.8	2.1	2.6	3.1	3.7	4.5	5.4	6.9	8.1	8.9	9.0	9.0	7.6	9.0	8.6	6.2	4.7	3.4	2.8	2.2	1.8	1.6	1.4	-15
	-24	-22	-20	-18	-16	-14	-12	-10	-8	-6	-4	-2	0	2	4	6	8	10	12	14	16	18	20	22		

Notes: —— ICAO boundaries

– – U.S. lateral boundaries

Representative intensity: 18 kilocandelas

Figure IV-6: Effective intensity distribution data in kilocandelas of a General Electric type FT34/HP flasher

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